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Industrial diagnosis is a process whereby an organization—factory, business, trading or industrial firm—seeks to discover the strength and weaknesses of its policies and the degree of implementation of these policies. The process is in many ways analogous to that of medical diagnosis. The methods used are those of operational research, and the main approach is a numerical one. The period required to carry out a thorough diagnosis of a major activity is measured in man-years. Industrial diagnosis has been known to give returns a hundred times its cost within as little as a year.

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INDUSTRIAL DIAGNOSIS

by

K. PENNYCUICK

Dr. Pennycuick is a mathematician who worked in British Army Operational Research during and after the second world war. He was also Director of Operational Research with the Overseas Food Corporation in Tanganyika. He is now in charge of the Operations Analysis Section at the head office of Imperial Chemical Industries Ltd.

INTRODUCTION

Every organization, however well run, is liable, owing to some change in external circumstances, to require modifications of its structure and policies. Sometimes an organization shows a symptom of ill-health calling for remedial action, but the cause of the symptom may not always be clear; before a cure is attempted this must be uncovered. The 'classic' symptom is a reduction in profits, and there are others—an increase in labour turnover or failure to realize an anticipated increase in profits, etc. Industrial diagnosis may be used either for the purpose of discovering the causes of symptoms, or of investigating the validity of current practices and policies.

For human beings it is usual to go at intervals to medical practitioners for a general check-up, or to visit dentists or eye specialists. In certain cases the patient will go for further advice to a diagnostician, who will usually confine himself to identifying the patient's complaint and referring him again to the original practitioner, who may then send the patient to some other specialist.

In management consultancy, however, the practice is fortunately simpler. An organization need not go to the general practitioner, then to the diagnostician, then back to the general practitioner, and finally to the specialist; it may call in the diagnostician from the start. This simplification is possible because, unlike the human being, very few organizations can readily review their own policies. Some, of course, do so, but it is surprisingly difficult for a man concerned with the running of an organization to take an objective view of its problems. For example, a manager may say: 'Our stocks of raw material seem to be rather large, we must reduce them.' An independent observer is more likely to inquire into the circumstances that necessitate carrying such stocks, and go on to ask if the right quantities are being held in the given circumstances. If they are, he will inquire whether it is possible to alter the circumstances so as to effect an economy, either in the cost of purchase and delivery of stocks or in the cost of holding stocks, by changing the methods of delivery and use.

Again, in contrast with the human being, it is most unlikely that any large activity would not benefit from a diagnosis, which is always likely to yield useful information about the progress of the organization. For an organization as for a person, however, self-prescription is not always a wise solution; to treat symptoms without treating their causes is rarely advisable, and therefore the manager can usefully call in expert assistance.

In this account of industrial diagnosis the emphasis is on organizations engaged in manufacture. The ideas discussed, however, can equally well be applied to any facet of human activity. The usefulness of a diagnosis will, of course, depend to some extent on the efficiency of the firm; spectacular results cannot be expected in the case of large and highly efficient concerns, although here a small advance in efficiency may be much more worth while than a comparatively large advance in a less efficient small concern. In public concerns, a recommendation for improvement often meets with a mass of inertia and prejudice which blocks change in the name of public interest. For example, take the rule in government departments that every penny of public money must be checked, in spite of the growing realization that sample auditing methods are just as efficient as, and more economical than, current practices; spending pounds to check pennies has little to commend it.

The main approach to the process of diagnosis here described is a numerical one; in consequence the methods used are not readily applicable in any field where evaluation on a numerical basis is difficult. Some problems in the field of human relations fall into this latter category. Research programmes provide another example, for their value may depend on how long it will take to bring a programme to fruition—generally an unknown factor—quite apart from the possibility that the programme may not be capable of being brought to fruition.

THE STRUCTURE OF A MANUFACTURING BUSINESS

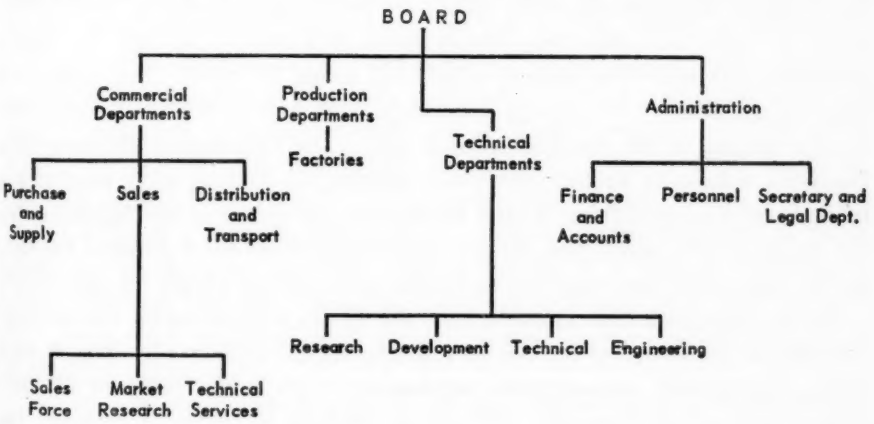
Any study of a manufacturing business must start with an inquiry directed to three main points: (1) What is the object of the business? (2) What are the resources employed? (3) How is the utilization of resources controlled?

It is easy when asking 'What is the object of the business?' to get involved in lengthy discussions on profits, service to the community and so on. It may be assumed here that the object of any business will include some element of profit and some social implications. The diagnostician, however, is concerned with the firm's field of operation and the type of customer it sets out to serve, and whether the activities of the firm form a coherent pattern. Incongruities should be noted, for they lead to loss of efficiency as a result of too great a variety of interests, although a proper diversity in the range

of products or services sold is not to be confused with lack of intergration. On the other hand, a distinction should be made between carrying a complete range for reasons of prestige and carrying a sensible range which can be obtained without waste.

There are four main resources used in manufacture, three of which—machines[1], materials and men—are sometimes referred to as the three M's; it is to a study of these that the inquiry must be mainly directed. The fourth resource—services—may be self-supplied through use of the three M's (e.g. a plant generates its own electricity), or it may be purchased from outside, in which case normal accounting methods should successfully deal with any waste. The three M's by themselves do not, of course, give a complete picture of a firm; but it is convenient to consider the firm as being made up of a manufacturing part, in which these three M's turn out goods for sale, and to regard the remainder of the firm as a control system for making the best use of the three M's.

There is probably no single 'best' control system for a given firm, nor is it easy to draw up a representative management structure which will be valid in all circumstances. Some functions can be located at several different parts of a management structure and still operate satisfactorily. On the other hand, this distribution of functions, particularly in large firms, is liable to lead to considerable overlapping and some unnecessary duplication. The figure below shows the first stages of a management structure of a large concern. Some explanation is necessary, for the diagram omits certain functions (which usually have their place at a lower level) and also suggests that each function is separate and distinct, which certainly does not correspond with the realities of industry; border-line activities of one department may appear to belong equally well to another department. It is not easy, for example, to distinguish between the Production Departments' care of their



1. In some circumstances the term 'machines and buildings housing them' would be more appropriate —chemical plant is a particular case.

machinery and the Maintenance Engineering Department's care of the same machinery; and problems of demarcation in the trade-union field in some industries are only too well known. Broadly speaking, however, the division of functions shown here may be considered to be satisfactory.

It is a function of the Commercial Departments to purchase raw materials, ensure that they are supplied at the right time, in the right place and in the right quantity and, in the same way, to see to it that new machinery is purchased and supplied. The Sales Department, in consultation with the Production Departments, decides upon the range of products to be sold and forecasts demand; this is more particularly the task of the Market Research Unit, which is part of the Sales Department. The business of the Sales Force is to dispose of these products. It is unwise to supply a customer with something which does not meet his requirements and is not in his best interest; at the same time the firm should try to minimize the waste which may be incurred by diverging from a standard range of products. With the Sales Force must be associated a Technical Services Unit which helps the customer to make the best use of the products he buys. The function of the Distribution Department is to ensure that the customer's order is delivered on time, and this clearly impinges on production planning in the factories.

Planning is the concern of the Production Departments. For present purposes we need only note that the Planning Division of the Production Departments must strike a balance between the interests of the manufacturer and those of the customer.

The technical functions are divided here among four departments, each of which may have further sub-divisions. The Research Department is likely to deal with everyday routine work (e.g. testing the quality of incoming or outgoing goods), making minor improvements in products or processes, and with long-term research aimed at more fundamental improvements. The Development Department works chiefly on the range of products, particularly so as to meet new customer requirements and also to expand the firm's activities into new (but usually adjoining) fields of effort. The Technical Department deals with process efficiency, and particularly with economic studies bearing on the provision of new plant. The Engineering Department's functions consist in keeping the plant working, in finding ways and means of improving or modifying it, and in drawing up technical specifications for the design of new plant. This differs considerably from the Technical Department's function of assessing the economic merits of proposals for new plant.

Of the Administrative Departments, the Finance Department has at least four functions: financing the business, preparing the accounts to comply with legal requirements, management accounting to show the progress of individual parts of the concern, and cost accounting in order to discover the profitability of each product. The Personnel Department is concerned with 'hiring and firing', with conditions of service, rates of pay (including incentive

schemes), training and amenities. It may be divided into sections for different types of employees. The Company Secretary and Legal Department deals with such matters as the Companies' Acts, contracts, estate business, etc.

So far there has been little mention of services specifically directed towards improving the over-all efficiency of the concern, although some mention has been made of the work of the Finance Department, of Production Planning and of the Technical Departments in this field. Responsibility for improvements in departmental efficiency always lies with the head of a department; the head of a concern is responsible for the efficiency of the whole concern. Both may find it desirable to call in specific services to provide the specialist knowledge which they may lack.

Technological improvement has already been discussed as part of the Research, Development, and Engineering Departments' duties. The other three main efficiency services in large firms go under a variety of names. Organization and Methods (or Office Administration) is generally concerned, as its name suggests, with organizational problems, efficiency of paper work, and utilization of office staff. Such a department is likely to be attached to the commercial part of the firm. Industrial Engineers, or Work Study, or Time and Motion (this term is fortunately dying out) can conveniently be placed within the Production or the Technical Departments, though it is sometimes found as part of the Personnel Department, because it is primarily concerned with utilization of manpower, and consequently with problems of remuneration. However, the Personnel Department is too remote from production problems for this arrangement to work satisfactorily. The third efficiency service, Operational Research, has in recent years begun to take a prominent place in the U.S.A., in Great Britain, and lately in Western Europe. This service is usually attached to the Technical or the Production Departments, an arrangement which is not altogether satisfactory, for Operational Research must deal amongst other things with policy problems at all levels, and should therefore have a direct link with the Board of Directors.

It may seem strange that we have made no mention of money as a resource; money in itself is not, of course, a direct resource but a means of providing the resources of manufacture listed above. Such questions as 'What is the return on capital, and how is this capital split between fixed assets and working capital?' may be asked when comparing the performance of different parts of the firm, or as a preliminary to financial operations such as raising fresh capital. They may also be asked at the end of a diagnosis when action is required. On the other hand, the diagnosis itself may have been prompted by asking such questions and getting answers which disclosed symptoms calling for diagnosis.

Another resource which may be of great importance is credit, but this again is money in another form. Nor has separate mention been made of land and buildings; but in a manufacturing concern these are likely to be

resources of lesser import. They may be rented, and in this case (as for purchased services) standard accounting methods should prove adequate, thus making the diagnostician's task that much simpler. However, in some kinds of business, land and buildings may be the prime resources.

An outline of a firm's management structure such as the one described above will enable the diagnostician to proceed to more detailed quantitative studies.

DATA FOR DIAGNOSIS—MACHINES AND MEN

The diagnostician, who is likely to be an outsider to the firm or even to the industry, will start by inquiring in broad outline about the range, quantities and values of the products manufactured. He will then ascertain how these goods are produced, i.e., what raw materials come into the factory, with what frequency and in what quantities, and what is done to ensure that they conform to specification. He will then follow these materials through their various processes, asking at each stage 'What is the utilization of machines, materials and men?' He must also know how these operations are controlled, and this involves examining the management structure, which may differ considerably from the skeleton given above. It might be necessary to find out exactly how instructions get to the man on the machine, whether these instructions are carried out to the last detail, or only in principle, or hardly ever, and what 'feedback' is available to show the actual progress of work.

So far the diagnostician's work is descriptive. He is now faced with measuring 'throughput' at particular points in the process, including output from the factory. This may necessitate inventing units of measurement, which is usually easy for an individual process, rather less easy for a machine, and very difficult for a whole factory. To start with, it may be necessary to collect detailed statistics of output per unit of time, both in quantity and kind, for individual processes connected with particular products, and to try from these statistics to evolve a common measure of output. The difficulties may be illustrated by some examples. It would be misleading, for instance, to measure the output of a foundry in terms of tons of castings, for this takes no account of differences in types and shapes; it is much more to the point to record the number of castings of a particular type. Weight (or volume) is likely to be a suitable measure only if the commodities in question are for all practical purposes uniform. Output of cement can well be measured in tons, but to measure output of milk in gallons is less satisfactory owing to variations in quality; and it is certainly unwise to measure output of an electric motor manufacturer in terms of total horse-power per year.

Once suitable units of measurement have been devised, the diagnostician

will return to the raw materials; he will classify them by types and quantities, ascertain which are the more important, and plot the routes of these through the factory. Branch points will be noted as leading to different end products or to alternative routes. Such information can conveniently be recorded in the form of a scaled-flow diagram. This may be complex, and in order to account for all materials it may be necessary to proceed machine by machine through the factory, inquiring 'What is the machine doing, how well does it do it, where does its material come from, and where does its product go to?' It is also necessary to find out what the machine did over a lengthy period and what it might have done instead. This inquiry will cover different methods of working, different times of work and different methods of manning; it will also cover idle time occasioned by waiting for material, routine replacement of worn parts of replacement required owing to breakdown, and time for cleaning and lubrication.

USE OF PLANT OR MACHINERY

At this point it is necessary to introduce certain concepts of the use of plant or machinery—the concepts of machine occupancy and of machine utilization. A machine is said to be occupied if it is working or being worked on. 'Working' implies running time only; 'worked on' also includes cleaning, preparation, servicing, repair, putting work on to the machine and removing work from it. A machine is said to be utilized only if it is working. Occupancy and utilization each should be expressed as percentages of both the 168-hour week and the paid week (48 hours, for example). The difference between machine occupancy as a percentage of the paid week and machine utilization as a percentage of the 168-hour week is likely to be startling.

In processes where the main cost item is depreciation of plant and replacement of worn parts, study of occupancy and utilization figures may provide sufficient data for a diagnostic study. If the difference between machine occupancy and machine utilization (relative to the same basis) is large, the most probable reasons are frequent breakdowns or short runs; the former presuppose old machinery, poor maintenance, or both; the latter imply an unsatisfactory order book or poor planning. Low occupancy of machines throughout the factory implies lack of orders, while low utilization of machines implies frequent runs of short duration. This in itself may not matter to the firm as long as the accounting and pricing systems are such that a proper financial return is being obtained from the machines. This, however, is not likely to be the case; a machine which is under-utilized is a machine that is being wasted, and if machine utilization is low something is radically wrong, even if machine occupancy appears to be high. A case for grave concern arises when there is a long order book and low utilization.

Even more serious is a long order book and low occupancy, for this implies starvation of machines simply because work does not reach them.

The question then arises whether this symptom applies to an individual machine or to the whole factory. In the latter case, it is likely that the balance between economy of materials and utilization of machines has been biased too much in favour of materials. This will be discussed later in connexion with materials. If, on the other hand, some machines in the factory are found to have a low utilization as compared with others, then the factory would seem to be faced with a problem of balance of plant, which can be referred for solution to the Engineering and the Sales Departments. The cause may be 'bottle-necks', or the fact that the pattern of orders has shifted away from that originally envisaged, which may in part be remedied by the Sales Force. Under-utilization of a particular flow line which is free from bottle-necks may suggest that these machines might be used for other work if further orders of the original pattern cannot be secured. It must be remembered, of course, that the correction of one bottle-neck may result in the creation of another bottle-neck elsewhere. A more difficult situation arises when machines towards the end of a flow line are under-utilized, and yet there is no evidence of any bottle-neck higher up the line. In such a case, a likely diagnosis would be excess of plant, and the remedy might be to obtain additional business for the part of the flow line which is under-utilized or, alternatively, to dispose of this under-utilized plant. If the plant is obsolete, the right answer may be to call in the scrap merchant.

So far, the discussion has been concerned exclusively with machine utilization. But man utilization is becoming more and more an accepted part of management, and in most diagnostic studies it is desirable to check on the efforts of the operator. Where one man is working one machine, low machine occupancy will be accompanied by a low level of man effort. But a low man occupancy may be accompanied by a very high machine utilization—if the process is fully automatic, for example, and the man spends most of his time watching the machine and taking only occasional action. A low man utilization is therefore not necessarily a cause for concern, but a very high man utilization may be one. If very high man utilization is accompanied by low machine utilization, there may be a case for inquiring whether the machine is not undermanned.

Machines which are manned by a crew of several men present rather different types of problems, but the general principles remain the same. If the man utilization is high and the machine utilization is low, it is likely that the machine either is not performing operations it ought to do or else is undermanned. If both man utilization and machine utilization are high, there is a case for inquiring whether the machine is undermanned. But if machine utilization is high and man utilization is low, the machine may be overmanned. The foregoing remarks can be summed up in the following tables.

TABLE 1. Machine performance

Symptom			*Diagnosis or further inquiry*
Occupancy per paid time	*Utilization per paid time*	*Utilization per 168-h. week*	
High	High	High	All well at this stage.
High	High	Low	Work more shifts?
High	Low	*	Short runs or breakdowns?
Low	Low	*	Lack of orders or bad planning?

* Must be low by definition.

TABLE 2. Man and machine performance

Symptom			*Diagnosis or further inquiry*
Man occupancy per paid time	*Machine occupancy per paid time*	*Machine utilization per paid time*	
High	High	High	All well at this stage.
High	High	Low	More men needed, or longer runs needed, or avoid frequent breakdowns.
High	Low	*	More men needed.
Low	Low	*	More work needed.
Low	High	High	Fewer men needed.
Low	High	Low	Fewer men and longer runs needed.

* Must be low by definition.

There remains to be considered the situation where one operator controls several machines. In this case, the diagnostician should at once suspect machine interference problems and inquire whether there has been any recent study of the optimum number of machines which can be handled by a single operator. If not, such a study is likely to be required, but this view should be confirmed by collecting data on the proportion of time lost when either the operator or the machine is idle and on the cost this loss entails. There is an extensive mathematical literature on machine interference problems.[1]

DATA FOR DIAGNOSIS—MATERIALS

The utilization of materials is a problem which requires different treatment for different industries. In the chemical industry, for instance, yield from a reaction is the relevant factor; in smelting, the relevant factor is similar; but in metal working, scrap, which can usually be salvaged for its metal value,

1. See, for instance, Robert B. Fetter, 'The Assignment of Operators to Service Automatic Machines', *Journal of Industrial Engineers*, Vol. VI, No. 5, Sept.-Oct. 1955.

must also be taken into account; in the thermo-setting plastics industry or in the wholesale clothing trade there is inevitable waste—defective products in the first case, cuttings of cloth in the second.

Utilization of materials 50 as to avoid waste receives adequate consideration in most factories where the material is relatively expensive and where there is little or no recovery value in residues, scrap or waste. Less care will naturally be taken where scrap can be re-processed with little loss. Nevertheless, in any diagnostic study it is necessary to inquire at each stage into the formation and disposal of scrap. An inquiry of this kind can lead to the discovery that some raw materials are more liable to create scrap than others. Such studies, rather than the bottle-necks discussed above, may provide a partial explanation of the reduction in throughput as the work proceeds down the flow line. They may lead to a recommendation for the improvement of process instructions, or the setting up of new methods of inspection with or without a quality control scheme, so as to avoid the formation of excessive scrap.

Excessive scrap, assuming that the machines are in good order, is almost always due to bad process instructions. This is particularly true of processes containing a large element of what might be called 'black magic'. Any process which is highly susceptible to the operator's judgement is liable to cause fluctuations in the quantities of scrap, and conversely, a high rate of scrap or wide fluctuations in the amount of scrap may lead to a diagnosis that process control is inadequate. Unfortunately, in many industries the 'cook it until it's done' school of thought is still prevalent; this was inevitable in the days when measuring instruments were not available, but today there is no excuse for it. Inadequate process control suggests the need for more experimental work on, say, optimum times and temperatures; and provision of proper temperature control devices and automatic timers is likely to improve greatly the quality and uniformity of the product. In processes in which machine speed is an important element, fixed-speed machines are generally to be preferred to variable-speed machines because they eliminate the factor of variability and judgement on the part of the operator. Such work may be costly in time and money, but it is essential when diagnosis shows inadequate process control. Almost any process in which the yield is sensitive to such factors as time, temperature, pressure, humidity and concentration is likely to benefit from studies of the effect of changes in these parameters. The information thus gained can be used for economic studies of the optimum utilization of plant.

But the amount of scrap produced does not depend on process control alone; the further problem arises of whether material rejected as such is really scrap, and in this respect efficiency of inspection is of considerable importance. Poor inspection can be very costly if it results in rejecting sound material or passing defective material. It is therefore essential to check on the inspection arrangements.

An aspect of utilization of materials which is not usually well enough understood is the cost of carrying too heavy stocks, although curiously enough the cost of carrying insufficient stocks is well known. From the diagnostic point of view, it is fairly easy to assess whether stocks of raw materials for work in progress are reasonable, too large or too small, although it is much more difficult to assess in a similar way stocks of finished goods awaiting sale. A first approach to the problem of raw materials is to inquire when the firm or factory last ran out of them. If the answer is 'never', then there is good reason to suspect that stocks of raw materials are excessive. It is not often realized that unnecessary stocks of raw material carried at the factory's expense can be even more extravagantly costly than stopping a factory for lack of raw material; and that even excessive consignment stock, i.e., material payable on use, may result in hidden price increases.

Three kinds of information are required with respect to the level of raw materials. First, it must be known how the raw materials are ordered; this will include the conditions of purchase. The rate of consumption of these materials must then be considered, taking into account the vagaries of delivery by the supplier. This information makes it possible to estimate the safety margin provided by the prevailing level of stocks. Lastly, the question arises whether the holding of stocks is causing inordinate expenditure. Costs of holding raw material stocks are particularly difficult to calculate; they are likely to be made up of the cost of the money locked up in the materials, plus the cost of storage, handling, deterioration and insurance.

It is thus possible, by means of rough rules based on the total stocks of material in the firm, or on the average or actual consumption, to calculate the correct quantities of raw materials which should be carried. A much better approach, however, is to postulate that stocks of raw material should be adequate to cover only vagaries in consumption, and that these vagaries should be controlled by careful production planning so as to avoid wide divergences from the average. If vagaries of delivery make it necessary to carry stocks at an appreciably higher level, then the diagnostician will recommend a change in methods of delivery. This recommendation, however, will usually be valid only for raw materials delivered in large quantities. A full load of a particular delivery vehicle may often be considered as an economic method of delivery; deliveries in quantities smaller than these are not usually economic, though they may be worth while in the case of very highly priced raw materials. Incidentally, it is correct to say that, as a general principle, frequent regular deliveries in modest quantities will always result in a lower average level of raw material holding than erratic deliveries of large quantities.

Initial diagnosis as to whether the quantity of material in course of processing (including material waiting to be processed) is reasonable or not is a fairly simple matter. It is merely necessary to know what amount of work

must be waiting in front of each machine at the beginning of each work period to ensure that the machine will not run out during that period; on that basis a calculation can be made for the whole factory. If the quantity of material lying about in the factory is appreciably larger, it would seem that money is locked up unnecessarily. The diagnostician must then find out why these additional quantities are carried and decide whether, apart from being convenient for general planning, they can be justified on economic grounds.

It was remarked earlier that low machine occupancy was always a symptom of lack of work, but it is not necessarily a symptom of lack of orders. In any manufacturing organization, one of the three main resources is likely to be waiting for the others: men may be waiting for a machine to finish a run before starting new work on it; a machine may be waiting for attention because the operator is handling another machine; materials may be waiting in front of the machine for either the machine or the man; and lastly, man and machine may be waiting for material. It is very unlikely indeed that any order book and planning system can bring about a situation where there is no waiting. If man and machine utilization is very high, it is probably because excessive quantities of material are awaiting processing. This may be unimportant if the material is cheap and if the value added by processing is comparatively high, but this latter assumption cannot be true at more advanced stages of the process, when the material will have acquired more value. It is fairly simple to calculate the desirable amount of material which should be in front of a machine; it is only necessary to find out the delay created by the preceding machine and to take into account factors such as different rates of working and different times of working of the machines.

Stocks of finished products are rather more difficult to contend with, partly because a simple rule—for example, to carry so many weeks' estimated sales in stock—appeals to many managers. But there is no golden rule for this purpose; the correct amount of stock to carry will vary from product to product, and possibly from season to season. Excess stocks may accumulate as a result of continued production at a time of temporary slackness in demand. The factors which a diagnostician must consider in assessing the desirable level of stocks of finished materials are the average demand, the fluctuation of that demand, and the fluctuation in the sizes of individual orders. It is not always realized that the smaller the average demand, the greater the relative stock required (in terms of weeks' sales, for instance). The volume of stocks required also rises with fluctuations in the sizes of the orders. Again, a commodity in frequent demand and for which orders vary little in size will not require more than a very few weeks' stock, particularly if it is a commodity which can readily be produced each week.

Such studies, combined with knowledge of the time taken to replenish

stock, lead only to ascertaining the stock level at which the commodity should be replenished. But the diagnostician must also tackle the problem of the quantity to be ordered for replenishment. This will be related to the quantity which it is most economic to produce, and this will in its turn influence machine utilization and length of run. In the case of a commodity bought for resale, the cost of manufacture will of course be replaced by the cost of order and delivery. Stock-holding charges will then include allowances for obsolescence of the product and for variations in cost according to the quantity ordered.[1]

To sum up, when a diagnostician finds that fixed rules are applied to estimate either the level at which stocks should be replenished or the amount by which they should be replenished, he can assume *a priori* that the levels and the quantities are wrong.

MULTI-FACTORY PROBLEMS

The diagnostic methods so far discussed deal with efficiency in an individual factory; they do not cover a situation where several factories make the same product; nor do they attempt to compare the efficiency of factories making different products. For the latter, objective answers seem to be very difficult to obtain, but factories making similar ranges of products can be compared by means of industrial diagnosis. These problems can to some extent be approached through accounts, but such an approach will be greatly facilitated by an understanding of what goes on in the factory. Comparing the efficiency of several factories making similar products is only an extension of the study of an individual factory. But comparing the efficiency of several factories making the same product is even easier than studying the efficiency of the manufacture of that product in a single factory.

The first stage in the diagnosis is to study—as in individual factory—the utilization of the three M's in order to discover the strengths and weaknesses of the individual factories. Some work of this kind has recently been reported.[2] It is in the highest degree unlikely that any one factory will be either the best or the worst in *all* processes, and it is the diagnostician's first duty to tell each factory manager which of his processes are lagging behind, and why. The reasons will usually emerge in the course of the collection of the necessary data. The next stage in the diagnosis is to consider whether the individual factories are making full use of their resources, i.e., whether orders are correctly distributed between the factories. This means inquiring whether there is enough business to keep all factories fully employed or whether for

1. As on machine interference, there is an extensive mathematical literature on stock control theory. See, in particular, T. M. Whitin, *Theory of Inventory Management*, Princeton, 1953.
2. See *Productivity Measurement Review*, Special issue, April 1957.

transport reasons it is necessary to have a multiplicity of factories. The final stage before proceeding to accounts is to compare management structures with one another, noting whether they differ in organization and how they differ in strength. Such an inquiry is likely to show differences between factories in staffing and facilities. The diagnostician will relate the differences to the efficiencies of the plants, and then express his advice in general terms, such as that staff seems to be inadequate or excessive; detailed recommendations for change should be the subject of separate studies.

The next task is to inquire more closely if there is real need for the number of factories in use. If all factories appear to have full order books, high utilization of resources and little prospect of expanding output, the diagnosis must clearly be that a new factory is necessary. In this connexion, it may be advisable to close one of the existing factories, especially if study has shown it to be so old and inconvenient that it could never match the efficiency of a more modern plant.

If, however, a study of a group of factories shows that there is spare plant capacity or room to install it, the diagnosis will be that there is probably a surplus of capacity in the form of too many factories. There should then be a separate study to discover how the same output can best be obtained from a smaller number of factories. This is going rather beyond the stage of diagnosis but is not an unreasonable extension of it. Successful treatment of this problem, however, will necessitate detailed accounting studies.

Where several factories are thought necessary because it is cheaper to move raw materials to the factory than finished products from the factory to the customer, the diagnosis cannot stop at the stage of inquiring into what happens at the factories; it must go on to the organization of distribution, i.e., methods of transportation, location of stocks if any, and flexibility of delivery to the customer.

If there has been no recent study of optimum location of depots, of the size of stocks of products in those depots, and of the contribution of each of the factories in supplying the depots, it will certainly pay many times over to have such a study made. If, in the multi-factory problem, there is also the element of insufficient capacity, actual or potential, an investigation of these factors is clearly required to determine where a new factory should be located.

Studies of distribution at the diagnostic stage need go no further than inquiry into alternative routes or principles. At first sight the shortest routes involving the least handling are likely to be most advantageous. Any departure from this rule (such as passing through unnecessary intermediate steps), even when hallowed by long practice, would suggest that further study is needed.

FINANCIAL DIAGNOSIS

So far, the diagnosis outlined here has been concerned solely with the utilization of the three M's without considering the profitability of the operations. This approach contrasts with much recent work directed by accountants to the problem of business efficiency. A good deal of work has been done, for instance, in the U.S.A., and lately in Great Britain on financial ratios.[1] The reason for our approach in the present study is that the mere fact that one part of an enterprise is relatively profitable and another part relatively unprofitable does not necessarily suggest that one is more efficient than the other. Nor is a business which makes an adequate utilization of its manufacturing resources necessarily profitable, or a business which makes an inadequate use of its manufacturing resources necessarily unprofitable. It is, of course, probable that a business having a high level of plant utilization will be more profitable than it would be if it had a low level of plant utilization. An approach through utilization of resources, however, will show where there is scope for improvement.

If the utilization of resources is shown to be so good that no worth-while improvement can be obtained, the diagnostician must turn his attention to the remainder of the firm, i.e., that part of the firm which has earlier been described as a control system for making the best use of the three M's. The conclusion will be either that the control system is not paying its way, or that the firm is not getting an adequate return on its activities. In the former case, the control system must clearly be re-organized so as to eliminate from it all but the most essential function.

In the latter case, the lack of adequate return must be traced back to the probable causes. One of these may be an incorrect price structure; for instance, insufficient allowances may be made in pricing for the high costs associated with short manufacturing runs or with a very wide range of products when a smaller range would be sufficient. Thus, while it is easy to calculate the costs of packing and of handling documents for products made in large amounts, it is much more difficult to calculate these costs for products made in small amounts because these cause a considerable disruption of routine. It is also necessary to take account of the loss incurred by setting up machines to new specifications for short runs only. Another factor which must be considered is the loss of profit incurred by interrupting normal production schedules. It is also difficult to calculate costs for products which may be disposed of at intermediate stages in the flow line to other manufacturers. Diagnosis may show that products which have undergone one or

1. See, for instance, E. M. Davidson, 'Inter-firm Comparison of Financial Ratios—their Value to Management', British Institute of Management, National Conference, November 1956; or H. Ingham and L. T. Harrington, 'Inter-firm Comparison—some Conditions of Success', International Conference on Inter-firm Comparisons, (OEEC) E.P.A. Project No. 379, Vienna, September 1956.

two processes only can never be a paying proposition. This does not imply that the product becomes more advantageous to the firm in proportion to the number of processes it undergoes in its manufacture; its cost indeed may rise but not necessarily its profitability, as some of the special plant needed for its manufacture may be useless for other purposes and remain idle for long periods.

In order to solve these problems, it is necessary to consider how cost accounting is done, and the relation between costs and throughput, particularly the effects of allocation of indirect costs. There is, of course, no such thing as a true cost of any one of a miscellany of products; nor is there such a thing as a true cost of a unit of production when all products are identical. There is however such a thing as the cost of a unit of production, at a standard rate of production and using a standard method of working. Even so, this cost is likely to be the cost of processing; it may be extremely difficult to compute the cost of materials and to charge depreciation correctly.

It may therefore be necessary to cast cost accounts in several different ways so as to be able to take decisions on pricing with some assurance as to their validity. This, of course, assumes that there is some room for manœuvre in the pricing structure. But such an assumption may not be true in an industry where there is gross surplus capacity; where capacity and demand are closely matched, however, there may be considerable scope for real saving through a proper appreciation of the meaning of cost accounts. It is not difficult to see that pricing undesirable orders so that customers are not encouraged to place them with the firm can, in the long run, be highly advantageous both to the customer and to the firm, especially if accompanied by economies in manufacture and consequent price reductions for larger orders. If these undesirable orders are not replaced by more desirable ones but are given to rival firms, the diagnostician may still sleep quietly at night in the certain knowledge that short or embarrassing orders given to rival firms may well result in a lowering of their efficiency!

Financial analysis on such lines should be capable of resolving a problem mentioned much earlier, i.e., that from a firm's point of view, low utilization of plant need not necessarily be unprofitable. Whether it can ever be desirable from a national or world point of view to under-utilize mass production plant for small orders is a quite different matter; though ultimately waste of any sort must react on whatever causes it, even if at first sight it results in profit.

In carrying out an industrial diagnosis, the use of accounts to gauge the progress of different parts of a firm must be carried out with great care; it is essential that the basis of computation be thoroughly understood and that it be the same throughout the period under review; it is also essential to understand the basis on which the cost of material and services is debited and the value of materials transferred is credited. These may appear to be

elementary points, but there is a considerable difference in the interpretation of accounts on the part of the man who draws them up and the man who receives and must act on them. Costs calculated on a short-term basis are often liable to be affected by abnormalities. During a short period maintenance charges may have been abnormally low or, owing to a major breakdown, abnormally high, and costs, if calculated without allowing for such abnormalities, can easily give misleading impressions about the efficiency of the plant. During a short period output may have been abnormally low or abnormally high, and as costs tend to rise when output falls and *vice versa,* here again costs would give a wrong impression about the efficiency of the plant, though not necessarily about the efficiency of the firm as a whole because the plant's low output may have been due to short orders. Another case in which costs computed on a short-term basis can be misleading arises when goods produced in the factory are in part transferred to another plant for further processing and in part sold. The cost with which the transferred goods are credited will affect the price of other goods in the factory. But this cost may vary a good deal according to whether it is computed on a short-term or on a long-term basis, because the relationship between goods sold and transferred may not be the same in both cases, and this relationship affects the cost with which the goods are credited.

The last situation to be discussed under the subject of finance and accounts is the one where plant is being under-occupied and where there is little prospect of substantial increase in the business. This situation occurs when there is too much machinery or plant available owing to a reduction in demand or because an anticipated increase in demand has not materialized. A likely diagnosis here is that the enterprise can never be sufficiently profitable, and further studies will be needed to determine whether its activity should be stopped and, if so, when. It is exceedingly difficult, and sometimes impossible, to answer these questions by studying the components of costs in accounts. A shut-down is certainly logical if an activity is losing money and there is little or no prospect that the demand will recover. But it may also be reasonable to cease an activity which is not very profitable when the initial capital invested in the plant has been recovered and the working capital can be readily released and re-deployed. If the original capital has not been recovered, it may be desirable to find ways and means of continuing until that capital has been recovered. In either case the diagnosis must consider both the efficiency and the structure of the control system of the firm. In other words, it must answer two questions: (a) Does the system secure the results required from it? (b) Are the results obtained worth what they cost?

EFFICIENCY OF THE CONTROL SYSTEM

The process of diagnosis will have shown to some extent whether the control system of the firm is working adequately in so far as it does what it sets out to do, i.e., to ensure that the incoming raw materials are converted to the customer's requirements in the most efficient manner. A control system must therefore ensure that raw materials are available when and where required, that the machine is ready to receive them, and that where there are alternative possibilities the operator is given the correct process instructions. It is quite clear that unnecessary waiting of machines for materials must be a sign of an inadequate control system, as will be the fact that the average time taken to manufacture an item is much longer than that indicated by calculations. These facts will however have come to light during the study of resources. A better approach to the investigation of the efficiency of a control system is to inquire whether instructions are carried out precisely. Strictly speaking, such an inquiry is an ideal impossible of realization because some rejects are unavoidable in any process. One should thus find out whether an order for a specified quantity of a commodity has any tolerance attached to it, and then discover the quantity of raw material necessary to ensure getting at least the minimum quantity required; otherwise a deficiency of one or two items may have to be made up. Studies of this nature should soon show how efficient is this part of the control system.

Study of incidence of overdue orders may then be undertaken. The first thing to be ascertained in this connexion is the proportion of completed orders arriving early, on time, or late, at the dispatch end of the factory. Too many orders executed too early will tend to congest the warehouse. In time of full activity, orders completed early through getting out of sequence will be matched by an equal number of overdue orders, unless the factory is operating well in advance of the order book. In any event the reasons for overdue orders must be ascertained. If the main reason is waiting for additional items to complete an order, it may be suspected that the requirements figures for raw materials are wrong. This would suggest a statistical analysis of requirements figures. If however it is a question of complete orders arriving late at the dispatch end, then either the orders have not been planned for an early enough start on the plant, or have not been planned carefully enough, or else the record of the progress of material in the factory is inadequate inasmuch as it has failed to reveal casual delays or delays caused by re-processing; the latter may be due to inadequate process instructions or to accepting orders for which the plant is not really suitable.

A control system of a different nature is required to deal with maintenance of plant. Diagnosing unsatisfactory maintenance is a great deal easier than providing a sound maintenance scheme. It is necessary to find out what kind of stoppage is encountered on machines, and whether the stoppages are such

that they can be cleared by the operator or would need a maintenance man; details of frequency and duration of stoppages will of course be required. It is also necessary to classify the reasons for stoppages—for example cleaning, lubrication, adjustment, inspection, replacement of worn parts, breakdown. The last two will usually be related; inadequate replacement of worn parts leads to frequent breakdowns (while too frequent replacement is of course unnecessarily expensive). Analysis of the life of the components between breakdowns or replacements may be worth while and should show whether breakdowns or replacements are predictable or not. If they are not readily predictable, it may be suspected that the replacement parts are not being strictly enough controlled to see that they conform to specification, or that the specification is not precise enough. Either of these assumptions can be checked by searching for correlation between physical characteristics of the replacements and their life. If this does not throw light on the matter, it may be that adjustment on replacement is not precise enough. On the other hand, if it is possible to predict the likely life of the component, the question arises whether proper advantage is being taken of this knowledge to make replacements at convenient times rather than waiting for a breakdown.

The time taken to provide a replacement part must also be considered. This involves examining the accessibility and reliability of stores organization. Any store that relies primarily on the memory of the store-keeper must be suspect. It should be possible to find without any difficulty any particular item in a stores' index, and then with no more ado go to the appropriate bin. If this cannot be done, a re-organization of stores is required. Similar considerations apply to the control of goods for sale; a store in which it is not easy to find items must needs be inefficient, for it must hide a considerable quantity of obsolescent material which is merely taking up space and causing confusion.

DIAGNOSIS OF THE MANAGEMENT STRUCTURE

It may seem strange that the efficiency of the management structure, which is almost the first subject to be considered in a diagnosis, has been left to the end. But it is only when the diagnostician has followed the process through the factory and considered the various ancillary parts of the organization that he can see whether the management structure fulfils its purpose. Each part of the management structure must then be considered in turn to ascertain whether its functions are clearly defined and whether they are not duplicated elsewhere. Then comes the question: 'Is all of it necessary?'

As an example of the questions the diagnostician should ask, let us consider the Sales Force. The first problem is whether the Sales Force has adequate information about such matters as the manufacturing cost of the

goods it sells, and particularly the effect of small orders on the working of the factory and the kind of products in the firm's range which are undesirable. The next question is how the Sales Force operates, i.e., how many customers there are to a salesman, what is the frequency of calls, the size of the order per call and the components of each order. It is likely that the answers to these questions will vary considerably from area to area, and a proper analysis should show whether calls are being paid at optimum frequency. If the frequency appears to be insufficient, there is clearly a case for enlarging the Sales Force. If, on the other hand, there is a preponderance of small orders and the business is not equipped to handle them, it is likely that the Sales Force is too large and is paying too frequent visits. If the number of calls per salesman varies very much from area to area, the question arises whether this is due to a sparseness of customers which involves considerable travelling between calls, or to inefficient routing. Duration of call is another factor which needs watching, particularly if it varies considerably from area to area.

The business of the diagnostician is primarily to explain why things are happening, and not to propose a cure. But often asking the question and explaining the symptom go a very long way to providing a cure. The reasons for this are largely psychological—the mere fact that a man knows his work is being investigated will produce extra exertion on his part, especially if he feels that a sympathetic interest is being taken in his problems.

CONCLUSIONS

A full diagnosis of a concern of any size is a lengthy business, for a great deal of data must be collected, collated and considered. Consideration may involve extensive mathematical analysis or merely simple logical thought. In either case it is most unlikely that one person alone can produce really satisfactory results, although there are occasions when an experienced diagnostician can point readily to probable causes of difficulty. These causes are likely to be already known in the firm; what will not be known is their relative importance. It is the lengthy process of diagnosis which sorts out the important problems from the unimportant ones. The most satisfactory way of undertaking a diagnosis is to set up a team composed partly of personnel from the firm and partly of outsiders specializing in the various techniques involved. The process is that of organization for operational research.[1] The period required to carry out a thorough diagnosis of a major activity is measured in man-years and may take a year or longer. This may involve a good deal of expense, but the probable benefit should repay this expense many times over. Industrial diagnosis has been known to give returns of a hundred times its cost within as little as a year.

1. In this connexion see Churchman, Ackoff and Ornoff, *Operations Research*, New York, 1957.

WATER AND ECONOMIC DEVELOPMENT

by

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INTRODUCTION

Water, air and soil are man's basic natural resources. His level of material civilization is reflected to a large extent in the degree to which he has mastered these three elements.

We never experience a scarcity of air, except on high mountains; we can rarely say that the earth lacks soil; but we hear more and more often that water is in 'short supply'. How ample or short are the supplies of fresh water? In other words, what are man's needs in relation to possible sources of supply?

For all his domestic and industrial purposes, man uses on an average 600 litres (l) of water a day, or 200 cubic metres (m^3) a year. This includes water for drinking, washing, cleaning, feeding animals, and industrial purposes. But since rainfall in many regions of the earth is not sufficient to produce abundant crops, we must provide on an average another 1,200 l/head/day, or 400 m^3/year, to irrigate some 500 square metres (m^2) of agricultural land. The total for domestic, industrial and agricultural purposes thus amounts to 600 m^3/year/head; and a community of one million people requires 600 million m^3/year or, in round figures, about 20 m^3 a second (sec). The world as a whole, with over 2,500 million people, therefore needs some 50,000 m^3/sec.

What does this 50,000 m^3/sec represent in terms of familiar sources of supply? A good tap in the bathroom spouts about 0.005 m^3/sec; a little brook runs at about 5 m^3/sec; whereas the biggest outflow of water on earth —the Guayra waterfall on the Parana River which separates Brazil from Paraguay—delivers some 14,200 m^3 every second of the year, in other words about a quarter of what the world needs to cover its basic water requirements. Smaller, though better known, 'taps' deliver amounts which are still enormous: the Niagara Falls, an average of 6,400 m^3/sec; the Victoria Falls, some 1,150 m^3/sec; and the Rhine Falls at Schaffhausen, 400 m^3/sec.

Viewed on an over-all basis, the supplies of fresh water available are more than ample to meet the world's present or future needs. Unfortunately, the water from the Guayra Falls is of no use to, say, South Australia, nor that of the Niagara Falls to the countries of the Middle East. Thus the picture changes entirely when we pass from the global to the national, or better, to the regional scale. In this connexion, let us consider the demand and supply position of three very different countries which have one thing in common —all three have started to husband their water resources carefully in order to meet the needs of an expanding economy. The three countries concerned are the U.S.A., the United Kingdom and Israel.

The U.S.A. is already consuming over two and a half times as much as the world average (4,760 l/head/day, against an average of 1,800 l/head/day). Britain (with 180 l/head/day) remains well below the average, because it lies entirely within a cool humid zone and does not practise irrigation. Israel (with 1,270 l/head/day) is at over two-thirds of the average, but this consumption represents 15 per cent of the average annual precipitation, against only 5 per cent for the U.S.A. and 2 per cent for the United Kingdom. If, as may well be desirable, Britain started irrigation in the south of England, its total consumption would grow by 150 per cent in the next twenty years, but even then it would not amount to more than 5 per cent of average annual precipitation. Over the same period, U.S. consumption is expected to rise by 80 per cent, reaching 9 per cent of annual precipitation, and Israel's consumption is expected to rise by 100 per cent, to reach 30 per cent of annual precipitation.

At a first glance, it would seem that none of the three countries mentioned above need have any serious water problems, since each of them possesses within it own boundaries resources which, if fully exploited and carefully husbanded, are sufficient to meet the demand. Optimum exploitation and good husbanding, however, imply not only the full use of surface and subterranean water resources, but also the co-ordinated use of both in water supply schemes, whether these be for local, regional or national grids.

Viewed from this angle, the position is unsatisfactory in most countries. More often than not, the existing 'water problems' can be traced to one or more defective links in the chain of optimum exploitation of total water resources in a given region of consumption. Such a view might seem to imply that 'water problems' are a purely technical matter within a given geographical framework; in fact, as will be seen later, they are governed not only by technical, but also by political, economic and social considerations. These, however, cannot be fully understood without first assessing the technical factors involved.

SHORT CUTS FROM THE OCEAN AND THE AIR?

When we speak of water resources, we mean water occurrences either on the surface of the land (mainly springs, rivers, freshwater lakes) or below ground (shallow and deep aquifers). In comparison with these, the two other kinds of water resources, namely fresh water derived from the oceans and artificial rainfall, will remain of minor importance for a long time to come—although they have been very much in the news in recent years.

As far as the demineralization of saline water is concerned, nothing is yet in sight here to compete with conventional sources of water supply, except for such rare cases as the production of drinkable water on board ship or in military establishments on arid coasts or desert islands. There are two kinds of commercial engines now used for this purpose—multi-effect engines and vapour compression plants—but the capital expenditure for these installations exceeds that for the costliest normal water supply plant. In addition, their running expenses are from ten to thirty times higher than those of natural water plants. All other methods, such as power plants using differences in temperature at different sea depths, solar distillation, freezing, chemical processing, and electrical demineralization, have yet to pass the laboratory stage. In extreme cases where high-priced water can be justified, it may be worth while to use one of the processes of salt-water conversion on a small scale; but mankind is still very far from irrigating the deserts with water from the oceans.

One limited aspect of salt-water conversion, however, deserves much more practical attention than it has received in the past—the withdrawal of groundwater *before* it becomes saline. Salty springs or highly mineralized aquifers have their origin—as do almost all waters on land—in rain-water, i.e., in a supply which derives from a pure source. But somewhere on their way, the eroding and infiltrating fresh waters come into contact with salt deposits or saline rocks and become briny. Quite often salination is caused not by a gradual accumulation of minerals on the long and tortuous way from the point of first contact with the earth to the point of emergence (spring), but by a sudden increase in mineral content near the outlet or underground place of storage due to a deep-reaching fault or to the vicinity of a buried shoreline or an ancient lagoon. If the aquifer which feeds the spring or groundwater is followed up-stream, fresh water will frequently be discovered. This was the case of the two major saline springs in Israel—Kurdani, near Haifa (50 million m^3/year), and Shuni, near ancient Caesarea (50-100 million m^3/year). In these two instances, from 50 to 80 per cent of the flow is expected to be salvaged in the form of fresh water by means of up-stream wells. There is no reason to assume that similar procedures cannot be adopted elsewhere, thus providing an economic means of upgrading salt water.

The other kind of water resource—artificial rainfall—is also very far from

the stage at which it could make deserts bloom. A realistic appraisal of our present state of knowledge shows that seeding techniques are capable, under certain conditions, of *increasing* precipitation from individual clouds. But it must be realized that precipitation can only be increased, not created, so that areas and seasons poor in clouds are not favourable for techniques of artificial rain-making. These techniques will therefore be of benefit, mainly in sub-normal years, to crops depending on normal rainfall. Other water supply sources may also benefit from them indirectly—by greater run-off into rivers and reservoirs, and by increased infiltration into ground-water. Optimistic estimates go as far as to assume a rise of local precipitation by 5-15 per cent above the norm as a result of 'milking' the clouds. But scientists agree that the best areas for experimenting with techniques of artificial rain-making are those which already have a good normal rainfall and where rainy periods might be lengthened and intensified.

From the point of view of water supply, rain-inducement techniques should therefore be regarded mainly as a means of enriching existing surface and underground resources, particularly in humid regions or in semi-arid zones with rainy seasons. Until we can rely on artificial rainfall to such an extent that water engineers may take into account the increase in rainfall thus produced when designing structures such as dams, reservoirs or pipelines, the best way to use any increase in rainfall is to let it augment the infiltration into underground aquifers for later exploitation through wells.

THE RIVER BASIN CONCEPT

When speaking of optimum exploitation and careful husbanding of water resources, we have purposely avoided introducing the concept of 'river basin development' or 'watershed management'. This concept, as propagated and exemplified during the last twenty or thirty years, implies a co-ordinated development of flood prevention, navigation, drainage, hydroelectric power generation, fishing, water sports, water abstraction schemes—all within a natural surface drainage area. As a form of regional planning, the concept of river basin development has exerted and is still exerting a profound influence on the economic life of many countries and on the degree of co-operation between administratively divided provinces. The fallacy of exploiting or protecting a river through isolated technical measures along restricted stretches of the stream bed is now obvious to everybody, and the policy of integrating naturally interdependent amelioration projects has been vindicated by solid achievements.

However, in their enthusiasm over the successes achieved in river basin development, many planners overlook the limitations of this concept. These are many, and not the least of them stem from insufficient knowledge of

ground-water conditions within and beyond the boundaries of the river basin, from lack of co-ordination between surface and underground water management, and from the fact that surface drainage boundaries are frequently irrelevant to water needs and to modern means of water exploitation and transportation. Together with these limitations often goes a disregard for the possibilities of economic improvement within various sectors of the watershed, or beyond its boundaries.

In California, the river basin concept no longer fits the needs of water distribution. The recently started Feather River project provides for the crossing of several watersheds over an area of 800 km length from north to south. Starting from a 5,000 million m^3 reservoir at Oroville, water will run through a canal down the Sacramento River Valley, be pumped through a giant pipeline up the gradient of the San Joaquin Basin, and finally driven through a tunnel across a high watershed into the Los Angeles-San Diego coastal district.

On the plateau of Mexico, where climatic conditions have favoured a considerable concentration of population and industry on both sides of the continental watershed, the river basin concept cannot be made the framework for water development. Already the Lerma tunnel and the Gran Canal unite, in the valley of Mexico, the river systems of the Santiago, which flows into the Pacific, and of the Panuco, which flows into the Atlantic. Future development in the same region may add another connexion across the continental divide which will result in hydrological interchange between four different large watersheds. It is significant that this interchange will comprise both surface and underground waters. As far as water supply is concerned, similar breaks through natural hydrographic boundaries will be necessary in other parts of Mexico.

In Central Europe, the upper Rhine by itself is no longer considered as a water development unit—it is viewed as such only in conjunction with the upper Danube region; the Rhine may be considered as a river basin only up to Basle.

The vast low plains extending over eastern Europe and parts of Soviet Asia between the northern oceans and the Black, Caspian and Aral Seas make the concept of single watershed management in a technological age almost meaningless. Trans-watershed entities already created and projects for still bolder schemes can no longer be understood in terms of the river basin concept as a basis for regional planning. This concept has been changed not only by technical progress, which has made possible the pumping of large volumes of water over great distances against steep gradients, but also by geo-hydrological research, which has weakened the very idea of the river watershed as a distinct hydrological unit. In Karst countries, surface and subterranean drainage boundaries do not normally coincide; and the same holds good for many volcanic terrains, which may be regarded as a

particular form of Karst. In semi-arid zones, surface river systems are so disjointed that run-off may involve areas differing widely from one year to another: one year the terminus of the drainage may be a debris cone at the exit of the wadi from a mountainous region; the next year the same system may debouch far beyond the mountain border in a desert pan; at irregular intervals the river may overstep all intermediate drainage bases and send its floods into the sea.

Investigations in other areas have shown that the water divide for surface flows does not coincide with that for subterranean flows. In northern Israel a clear line divides the western surface drainage of the Galilean-Judean mountains directed towards the Mediterranean from the eastern surface watershed directed towards the Jordan and the Dead Sea. But this hydrographic divide does not correspond to that for the subterranean watershed —as proved by many wells. While the flow of rivers increases in volume with growing distance from the divide, wells placed on the subterranean watershed are capable of yielding similar amounts of ground-water whether they be in the vicinity of the drainage bases or farther away from them. This means that from the point of view of water supply, underground aquifers may behave like a continuous reservoir stretching across and beneath the surface watershed. In exploiting them, the water planner may largely disregard the river basin concept.

SURFACE AND UNDERGROUND RESOURCES

The conclusion to be drawn from the facts is that a generally valid concept of water development cannot be based on surface water phenomena alone; it must to an ever-increasing extent take into account the phenomena of underground reservoirs.

This shift in emphasis from the visible to the mostly invisible manifestations of water circulation is of very great economic importance. It cannot be traced to a single discovery; knowledge of underground hydrology has been gradually accumulating for the last fifty years. Advanced ideas on the statics and dynamics of underground water movement and accumulation have been put forward by a small number of scientists, particularly by Karst hydrologists, since the beginning of the century. The classic Karst country on the borders of Yugoslavia, Austria and Italy, where rivers disappear into the bowels of the earth and where the existence of large underground caves facilitates direct observation of internal water circulation, has encouraged hydrological studies on the 'pathological' behaviour of water. These studies in turn have stimulated the re-examination of concepts based on the experience of countries with a 'normal' hydrological cycle.

Another field of 'pathological' studies in hydrology has been developing

recently through research on arid zone hydrology, assisted by Unesco's programme in this field. While in most humid countries surface run-off appears to overshadow all other hydrographic phenomena, and Karst regions exhibit the overwhelming influence of underground drainage, arid zones are characterized by the irregular periodicity of surface run-off coupled with enormous evaporation losses.

A third 'abnormal' type of hydrology is shaping on the horizon owing to research connected with the present International Geophysical Year—the study of the petrified water cycle in arctic and antarctic regions. There the time factor in the preservation of solidified water masses above and below ground throughout geological periods pushes the annual cyclic movements completely into the background. Semi-arid, arid, Karst and glacial regions cover between one-third and one-half of the land surface of the world!

A modern theory of the hydrological cycle and of water management, if it is to be of general validity, must therefore embrace and unify the results of knowledge pertaining to 'normal' and 'abnormal' water occurrence and behaviour. The old mechanical view of a short-term cyclic moisture movement (ocean—air—precipitation—run-off—infiltration—back to ocean), conceived of as an uncontrolled process of nature, must give way to a new view embracing time factors, numerical relations between the various phases of the cycle, and the power of technological man to interfere with those stages of the cycle which can be exploited for his benefit. An artificial hydrological cycle, consisting of numerous elements created by man, will become part of the natural cycle and modify it. Artificial rain, artificial recharge, artificial re-cycling, artificially raised and depressed ground-water levels, artificially reduced evaporation, artificial dissolving of ice masses—all these elements, unheard of a few years ago, will be increasingly introduced not only into the theory of the hydrological sciences, but into the techniques of water management.

Before considering further the new technological aspects of water manipulation, particularly those relating to ground-water, let us look briefly at the quantitative relationship between surface and underground waters. It is true, of course, that almost all water below ground was once surface water, but most of it did not occur above ground in a form useful for supply, e.g., streams, lakes, springs, etc. During any stage of the cycle, water in a usable form is found in a much larger proportion underground than on the surface. On a world-wide scale, the relation might be around 2:1 in favour of ground-water. This figure, however, does not includes reserves. By reserves are meant those water sources which do not take part in the annual or short-term cycle, and which were deposited in hollows or in formation reservoirs in the course of recent geological periods during the last 500,000 years, but mainly during the later glacial periods, i.e., 20,000 to 100,000 years ago. The largest surface water remnants of this type are the North American lakes. But the

volume of all fossil surface deposits is only one-tenth to one-fifth of that of underground reserves.

Water exploitation in the world is thus in a paradoxical state: some 90 per cent of mankind's needs are at present derived from surface sources or surface artificial and natural reservoirs; but these represent at most 20 per cent of the world's total water resources.

THE CASE FOR SURFACE WATER

This unbalanced state of development is accounted for by six cogent reasons, and it is only recently that these have really lost much of their validity.

First, surface waters abound in the regions of the great ancient civilizations and in the areas now populated by modern industrial nations. Indeed, this abundance was one of the main factors which made cultural and economic growth possible.

Second, surface water occurrences can be measured with relative ease, and this facilitates planning, transport and distribution. In fact, the development of mathematics and mechanics in the ancient world owes much to the necessity of finding practical and equitable means of deviating and dividing springs and river flows.

Third, although wells and tunnels have been dug since the beginnings of settlement, the seemingly erratic occurrence of ground-water made its exploitation rare. The cost and labour necessary to lift it to the surface was another stumbling-block in a non-technological age. The idea of dealing with known volumes of surface water which can be managed without any significant expenditure of energy became so firmly ingrained that even today, with all the facilities offered by modern technology, the progress of ground-water development is often unjustifiably blocked.

Fourth, direct transport by gravity of surface waters from rivers or dam reservoirs to places of consumption is possible in most cases, because stream water can easily be deviated on its way from the mountains to the sea. Until recent times such flow by gravity was the one and only mode of transporting water, except for such small quantities as could be lifted by buckets or bucket wheels. By contrast, ground-water accumulates not only below the ground, but in most cases at low elevations—at the foot of the mountains, in valleys and coastal plains—whence it has often to be pumped to higher altitudes. Although a natural gradient is no longer a pre-condition for an economical water system, a kind of gravity complex still permeates the thinking of laymen—and not only of laymen!

Fifth, according to the classical concept of the hydrological cycle—which is still held by many soil scientists and water engineers—practically all underground waters ultimately return to streams and lakes. Thus any expansion

in the use of surface water will finally also embrace the temporarily inaccessible underground resources.

Sixth, there is the historical fact that economic and political power over local, national and supra-national entities has in the past been exercised by virtue of the effective control of waterways. The history of ancient Egypt in the middle and lower Nile Valley can be interpreted to a large extent in terms of the influence of the Nile waters on the monolithic system of government and of the vital importance of the stream canals on the organization of the economy. Tribal, feudal, national and imperial power was, and frequently still is, based on the ownership of key springs and river-heads. The fight for independence through progress in water technology is a recurrent theme in history. In biblical times, a unique development of techniques for collecting and preserving rain-water made the Hebrews masters of their own fate in the Judean mountains, surrounded though they were by powerful neighbours in the water-rich Mediterranean coastal plains and the Nile and Euphrates-Tigris valleys. Israel's present rule over the arid Negev owes much to the fact that there were modern wells in each of the settlements at the time when the modern State of Israel came into being in 1948.

RISING WATER DEMAND

The steep rise in water demand, which is out of proportion to the rate of population growth, and the rapid extension of material civilization into areas which are poor in water have brought about changes not only in the traditional methods of water supply but also in the thinking that is at the back of them.

In accordance with established practice, the demands of the various water users are made first and foremost on surface resources, and the problem cannot be solved merely by dividing available supplies between the claimants, for the interests of users are often opposed to each other. Thus, navigation requires a minimum depth of water, and abstraction from the stream bed for irrigation, particularly during the dry season, may depress the water level below the minimum water mark for navigation. A lake serving as a recreational centre for a metropolitan area cannot function at the same time as a receptacle for untreated sewage. Hydroelectric installations, although they do not consume water, may lead to a clash of interests between farming and industrial communities. The former may need the water for irrigation of high-level inland basins or plateaux and may want to pump it up to levels near or above the head of the stream. Industries, on the other hand, may wish the water to run down to low levels for optimum exploitation of the power potential and for sale to industrial communities on terms more advantageous than farmers could afford. The fast-growing chemical, petro-

chemical and, above all, nuclear industries not only need large volumes of water for production processes, but must also make use of rivers as the most convenient and cheapest means of waste disposal. But this may change the chemical and bacteriological composition of flowing water below the point of discharge so as to make it unfit for fish-life, irrigation or human consumption.

An ever-recurring clash of interests which preoccupies public authorities everywhere is that between irrigation, on the one hand, and industrial and urban needs, on the other. Industries and municipalities can afford to pay from five to twenty times more for water than can agriculture. The simple rule of economics that human consumption must get priority over industry, and that industry must have priority over agriculture, cannot be followed to its logical end as far as water use is concerned, for it would be the death warrant of many highly cultivated irrigated lands. Political decisions on a high level are the only means of solving an economic conflict of this kind.

The scramble for water, which has been particularly accentuated in the last twenty years, is due of course to a general rise in living standards all over the world. Whether each household in a village gets its first direct water supply instead of having to draw from a central pump or a spring pond, or whether the recently promoted Mr. Jones installs a swimming-pool in his garden, the result is the same—increased water consumption per head and higher demands on resources. The birth of an industry like air-conditioning creates a new and important customer for water. A rise in the standard of living of the working man in Europe and the consequent increase in his consumption of citrus fruit mean an increased acreage of irrigated groves in California, Florida, Mexico and the Mediterranean countries.

Unfortunately, it is impossible to evaluate precisely the increase in demand due to all these factors, as statistics of water consumption are not yet available on a world-wide scale. We must therefore look at individual cases which exhibit significant trends and for which statistical data are available. An analysis of these data leads to certain general conclusions which are valid for those regions, both humid and arid, where the economy is developing at a more or less steady pace.

First, the withdrawal and use of water increases from three to ten times faster than the rate of population growth.

Second, urban and rural consumption (irrigation not included) represents about 10 per cent only of the total water consumption and increases in the same proportion as the latter.

Third, the proportion of water used for irrigation increases much more slowly than that used for industrial purposes. Although in the early stages of economic development irrigation consumes more water than all the other activities combined, the quantities thus used tend to become stabilized, while the amounts used by industry increase rapidly with the progress of industrialization and ultimately outstrip irrigation requirements.

Fourth, water withdrawal from underground sources is increasing probably twice as fast as that from surface sources. The relation between surface and underground water abstraction is, however, still overwhelmingly in favour of surface sources; in Europe, it varies between 20:1 and 5:1; in the U.S.A. the ratio is about 4:1. Present trends and technological possibilities suggest that during the next twenty to fifty years this ratio may be somewhere between 3:1 and 2:1 in humid regions, 2:1 and 1:1 in mixed humid and arid regions, and 1:1 and 1:2 in arid and semi-arid regions.

As far as the latter are concerned, it is to be noted that the advance of civilization into these water-poor regions is spearheaded by the development of oil production and by large-scale irrigation projects. Deserts and semi-deserts, particularly in the Middle East, have not only become the most important centres of actual oil production, but they also contain the major part of the world's oil reserves. Now, though the saying goes that oil and water do not mix, oil requires a great deal of water to become a commodity, whether it be for prospecting, producing or refining the crude oil. For each barrel of oil sold on the market, the oil industry uses at least twenty barrels of water. In fact, oil and water go together in more ways than one, for the development of oil production and refining brings great wealth to previously destitute regions and thus promotes a rapid increase in water consumption through urban, industrial and agricultural development.

As for irrigation, its advantages in semi-arid regions have now been rediscovered by modern nations some 1,000 to 1,500 years after the classic irrigation systems around the Mediterranean fell into ruins. Ample sunshine to promote plant growth, and a productive season extending throughout the year offer almost ideal conditions for agriculture in these regions—if independence from the vagaries of rainfall can be secured by means of irrigation. In this way new areas for food and industrial crops have been put into cultivation, not only as a result of national policies in the semi-arid regions of western and southern U.S.A., of southern Russia, of northern Mexico, of central Australia and of southern Israel, but also within the international framework of aid to underdeveloped countries, as for example in India, Pakistan, central and north-western parts of East Africa, etc.

It it too early yet to speculate on future developments in the field of nuclear power, but this new source of energy clearly opens up tremendous possibilities for arid and semi-arid lands. The production and use of nuclear power do, however, require very large amounts of water.

This steep rise in water demand has greatly stimulated the search for ground-water resources, particularly in seasonally dry areas. The stress on ground-water supplies is accentuated by the need for underground formations to be used as storage reservoirs in order to prevent evaporation which, in arid regions, may amount to 1.7-3.0 m depth per year from open water surfaces, against 0.3-0.6 m per year for humid regions. This trend towards

underground water storage, which also manifests itself in humid regions, owes much to similar developments in the field of oil-and-gas reservoir engineering.

It may therefore be concluded that there will be an increasing call for arid zone water management, which means in effect the exploitation of ground-water.

THE CASE FOR GROUND-WATER

As was said earlier, the arguments in favour of the use of surface water have recently lost much of their validity; and there has been a growing awareness of the advantages of ground-water exploitation and of the necessity of operating both systems in unison with each other. The way they are co-ordinated and the quantitative relationship between them are governed less and less by traditional considerations of water supply practice; the emphasis has shifted from short-term isolated benefits to long-range over-all advantages. The factors that are taken into consideration are not only the quantity and the direct profitability of a supply, but also its quality (mineral content, bacteriological count, turbidity, temperature), the security it offers in emergencies and its regularity over periods of drought and abundance, as well as its side-effects on health, drainage and soil structure. Experience has taught the engineer and the administrator that short-term views and restrictions in building water schemes often lead to the necessity for unforeseen transformations resulting in costly changes or even in the scrapping of expensive installations. Having inquired into the advantages and disadvantages of surface water, let us now put the case for ground-water.

We have already seen that the total amount of ground-water greatly exceeds that of surface water. Since ground-water reservoirs also occupy a far larger space than river-beds and natural and artificial fresh-water receptacles together, their water-table fluctuates only slightly in response to the annual in- and outflow. A succession of dry years may radically diminish stream flows, but ground-water reservoirs of even medium size are never quickly depleted. Even gross overdraught, as practised in central Texas, may go on for decades without exhausting the supply. Indeed, ground-water, because of its preponderance and slow movement, acts as the main compensating source of stream flows during periods of drought; more than one-third of river water originates as out-seeping ground-water.

Moreover, the slow movement of water into the ground and through porous formations (usually several metres, several dozen metres or at the most a few kilometres per year, against several kilometres per hour for moderately quick streams) results in the mechanical and biological purification and diffusion processes which turbid or otherwise polluted surface water

undergoes in the course of its peregrinations through the earth. Properly guarded and exploited underground aquifers are the best insurance against the spread of water-borne diseases. In addition, the permeable subsoil gives to the water a mineral content which in most cases is beneficent to man, beast, soil and plant. To a much higher degree than lake water or run-off from rivers, ground-water can be considered as dilute food and medicine for life on earth. Soils irrigated with ground-water require less fertilizer than river-irrigated lands. It is interesting to note that it was the use of ground-water that led to the discovery of the influence of fluorine on tooth decay; it was found that children getting their water supply from underground aquifers—which are relatively rich in fluorine—showed a lower incidence of tooth decay than those using surface water. This discovery led to the artificial enrichment of water supplies with fluorine, a practice which has now become current in several countries.

Another advantage which ground-water enjoys over surface water is that it is much less subject than the latter to daily and seasonal temperature variations. Ground-water reservoirs do not freeze, except in the high northern latitudes; nor do they become too warm in hot climates. Aquifer exploitation reduces therefore the range of artificial heating required in the cold season, and provides a convenient coolant in the hot season. The roofs of superimposed formations protect the ground-water from the more violent vagaries of the climate.

This shielding of ground-water from atmospheric conditions is of particular importance in the coming age of nuclear power; contamination from atomic fall-out, an ever-present danger for surface waters, is reduced almost to nil for subsoil reservoirs. For the same reason, underground aquifers are practically invulnerable to aerial attack, in marked contrast with surface reservoirs—as was demonstrated during the last war by the successful destruction from the air of the central water reservoir of the Ruhr district (the Moehne dam) in a matter of hours.

Reference has already been made to evaporation losses, and these clearly are much lower in the case of underground aquifers than in the case of surface occurrences. In fact, an aquifer does not lose any water by evaporation unless the water-table approaches ground-level. In such a case, it is usually possible to stop evaporation by pumping, and thus depressing the water-table artificially by a few metres so as to remove it from all contact with air. This operation results not only in the preservation of subsoil water resources, but also in the conversion of the subsoil formation into an evaporation-free storage reservoir capable of receiving any surplus of surface water. This is particularly advantageous in dry countries, where high evaporation losses from surface reservoirs and the irregularity of floods make dams a hazardous undertaking. In arid zones the retention of floods through artificial recharging into the ground is often the only economical means of

retaining water for later consumption. In humid regions, the main argument in favour of underground storage is not the reduction of loss through evaporation, but the purification and retention of surface water, which otherwise would vanish into the sea.

The lowering of a water-table and the draining of over-saturated lands result in additional economic advantages, for a water-table which is too near the surface, either periodically or permanently, has an adverse effect upon living conditions and human activities. A constant high humidity on the ground reduces resistance to diseases; a water-logged soil cannot filter waste and flood water; excessive humidity favours the growth of weeds and hampers agricultural production, while the building of houses on seasonally swampy grounds is usually an expensive business. In fact, the indirect economic advantages of lowering a water-table may more than justify the cost of drilling and pumping.

There is another aspect of ground-water schemes which strongly appeals to planners and administrators—and that is their flexibility and the gradual way they can be put into effect. Most surface water projects, especially those based on dams, cannot be built up gradually, but must be entirely completed before they can be put into operation. When the work is completed, large quantities of water suddenly become available from one day to the next, but usually this water cannot be fully utilized until after a certain lapse or time.

This rigidity and abruptness in the financing, construction and operation of surface water schemes may be contrasted with the flexibility and gradual development of underground water projects. Unlike surface supplies, which are dependent on single points or lines in the landscape such as spring pools, dam sites or rivers, ground-water supplies are dependent on aquifers extending under areas of tens, hundreds or thousands of square miles. Points of extraction (wells) can thus be numerous and widely spaced. A ground-water development project can proceed slowly from small beginnings and develop gradually into a very large scheme in accordance with demand and with the performance of the water-bearing formations. It should be remembered that the development of agriculture through irrigation represents a step by step growth of knowledge on the part of many individual farmers acquired over many years. Dumping water on the land is not irrigation, and it often creates as many problems as it attempts to solve. The sudden appearance of large volumes of water 'on the market' also tends to depress the price of water. Now water is a commodity like bread or oil, and should be paid for according to its production costs and to its value to the different consumer groups; it certainly should not be wasted by unduly depressing its price.

Lastly, water works based on ground-water, or at least not solely dependent on big river or dam schemes, give the citizen a fuller understanding of the all-pervading and complex functions of water in nature and in organized human activities. Sources of supply becoming gradually available and

distributed over wide populated areas educate the user and make him aware of the need for economy and for close co-operation with the water planner, the water-works manager, the banker and the government. Nowhere do the needs and interests, the rights and obligations of individuals and groups meet more closely than in deliberations on water policy and management. This co-operation and co-ordination of activities democratizes not only the water business but also the community that is built around it.

TECHNIQUES OF GROUND-WATER DEVELOPMENT

It now remains to inquire into the techniques by means of which these potential advantages of ground-water may be translated into concrete achievements. The techniques pertain to exploration, installations, transportation, storage and exploitation.

Exploration

The greatest stumbling-block as far as the appraisal and exploitation of ground-water resources is concerned is the invisibility of these resources. 'Water finding' had thus become a field dominated by mysterious gadgets ranging from a twisting twig to an electronic pendulum, and cranky theories on subsoil water movement are still so prevalent that the first task of the hydrologist is a psychological rather than a technological one. More often than not he has to explain that he is not just looking for water—some water can be found almost anywhere—but for the existence of water-bearing formations which fulfil certain conditions, in particular those relating to size, the mechanical and chemical properties of the water, the dynamics of inflow, of subterranean movement and of outflow. Unlike oil, water that is under the ground is not always usable. Under modern conditions, water exploitation from aquifers must be done on a very large scale; a member of a prosperous nation requires on an average as many litres of water a day as he requires of oil in a whole year.

In many other respects, however, exploration for water resembles exploration for oil. Both have become highly scientific techniques requiring teams of geophysicists and engineers working in close co-operation with economists. The geological and physical principles used in exploration and in the study of reservoirs are the same for water and oil. But, of course, the former is much more abundant than the latter.

While oil exploration makes use mainly of seismic and gravity methods, because of their great resolving power in depth, water exploration is dominated by geo-electric methods, which are versatile and cheap. It can be successfully conducted by a team of individual specialists and experts

operating under the supervision of a hydrologist or a geologist. The drilling equipment used for trial and production boring is the same for oil and water, except that in the case of water the rigs are lighter than for oil drilling because of shallower drilling depths (500-1,500 m for water, against 3,000-7,000 m for oil). Oil boring also makes much greater use of continuously drilling rotary equipment (to penetrate the upper oil-poor layers of the earth) than does water boring. Lastly, a fairly complete picture of the underground formations can be gained by using the tools of paleontology (geological dating), geochemistry, microscopy, electrical logging and other techniques in conjunction with data from surface prospecting and from geophysical sounding.

It is clear that the traditional attitude towards 'water finding' has no place in water supply planning. But while planners and administrators never hesitate to put a large staff of technical experts in charge of preparations for a dam scheme, they often expect a single geologist to locate well sites in a matter of days—and then go on blaming the geologist or the 'erratic' nature of ground-water when the well field does not perform according to expectations. If the amount of work and technical knowledge put into the preparation of ground-water projects were comparable to that devoted to the preparation of a dam scheme for a surface reservoir, the risk of failure would be no greater in the one case than in the other.

Installations

The progress achieved in well installations and pumping equipment in the course of the last two generations may be compared to the technical revolution which replaced the sailing boat by the modern ocean liner. Formerly, one of the greatest obstacles to ground-water exploitation was the difficulty of piercing a water-bearing formation to a depth of more than a few metres; and when water was eventually struck, further progress was halted either by the fact that man could not work under water, by the fluctuations of the water-table or by the very restricted capacity of the pumping equipment available. Nowadays pumping capacities and depths from which water can be extracted through shafts or bore-holes are practically unlimited. There are still, of course, some limitations imposed by economic considerations—for example, the amount of power needed for exploitation—but for all practical purposes, it may be said that all useful ground-water can be lifted to the surface at a cost consistent with its value. In the region of Beersheba, south of Jerusalem, for millenia the roaming ground of nomads, wells of 300 to 600 m depth are now being installed, the pumps raising form 100 to 500 m^3/hour from a water-table 200-250 m deep. The water is cheap enough not only for urban and industrial purposes but also for irrigation.

The process used in water boring is that of differential exploitation; it

consists in lowering perforated or 'blind' (unperforated) pipes into the bore-hole in the exact position, the perforated pipes serving for the outflow from an aquifer, the 'blind' pipes for shutting off a formation or an aquifer or aquifers which are unsuitable for exploitation. The same and other techniques also serve to prevent silt or sand from entering the bore hole. Filters are used as a pre-cleaning medium to purify the water mechanically before it reaches the surface and to keep the bore-hole in a good condition. The water is lifted from the bore-hole by means of the modern turbine pump driven by an electric motor or a diesel engine.

Transportation

Progress in water transportation has benefited surface as well as groundwater development, and has made possible a close co-ordination between supplies from both sources. The technological limits for long-distance transport of large quantities of water, whether uphill, beyond the surface watershed or across natural barriers, have disappeared. Iron, steel, and low- or high-pressure concrete pipelines can transport large volume of water at great speed and at low cost. The laying of pipelines has been freed from hand labour by machines which transport the pipes to their location, dig the bed, connect the pipes together, wrap the tubes with material for protection against corrosion, lower the sections into position, and control the installation when it is fully working. The ingenious combination of cement, steel and plastics in pre-stressed concrete pipes introduced only some fifteen years ago has brought an economical and technically satisfactory solution to the problem of transporting large volumes of water over the long-distances made necessary by the size of modern water works. Without such pipelines, the idea of regional or country-wide water grids, similar to those for electricity or for oil products, would have remained a dream.

High-pressure pipelines enable the engineer to conduct water along the most economical routes without incurring the considerable expenses necessitated by the servicing of canals and low-pressure pipelines. This long-distance water transport at low cost makes possible the development of semi-arid regions by drawing water from other parts of the country where there are surplus supplies.

The economic consequences of the progress of water technology are of such importance that since 1952 the Economic and Social Council of the United Nations has repeatedly advised its Member States to give the highest priority to large-scale integrated water schemes and to establish national water commissions or boards at cabinet level.

Underground Storage

The artificial recharging of subsoil water reservoirs cannot be considered as a new technique, since it has been practised in isolated instances and in a rudimentary way for centuries. The deviation of floods in semi-arid zones —as old as irrigation itself—was used not only to moisten the top soil, but also to enrich shallow underground aquifers, from which the water either rose slowly to the surface during the dry season or was bailed out from wells a few feet deep. During the last century, wells were drilled near towns situated on river banks in the temperate zone into gravel deposits accompanying and underlying the river, i.e., into permeable sediments which were in hydrological contact with the river-bed; these wells gave a continuous high yield in dry years. In addition, the water from the wells was subjected to natural filtration, which gave it a quality superior to that of the river water itself. Since the connexion between surface water and ground-water in these cases was obvious, the step from natural to artificial infiltration in coarse soil near river banks was clearly indicated. What has made the recharging of underground reservoir formations a new technique of fundamental importance to water supply is not so much the discovery of a new principle as the recognition of the fact that induced recharging represents perhaps the most important change man can impose for his benefit on the natural hydrological cycle.

When the surprising feature came to light that underground reservoirs were about ten times larger than surface reservoirs, hydrologists began to think how this gift of nature could be put to good use. The old rule governing aquifer exploitation—that only so much water should be withdrawn as is put back by natural average replenishment—suddenly appeared as an unnecessary servitude. Why not exploit the available vast quantities of fossil ground-water and free the underground storage space from past accumulations in order to make room for surface water which would otherwise run to waste into the sea or evaporate into the air? Why not lower a water-table permanently if, as a result, land could be drained, run-off diminished, evaporation through the soil reduced, flood dangers restricted, natural infiltration increased, and, lastly, extractable underground reserves raised? There was obviously something wrong with the assumption that the surface run-off from a river-basin constituted the limit of possible development of the combined surface and ground-water resources of the basin.

The modern hydrologist who answers these questions has, of course, at his disposal technical means and knowledge which were not available to his predecessor fifty or sixty years ago. He can point particularly to the great store of information on subsoil reservoir engineering gained by the study of oil deposits, though he might add that the knowledge of the oil geologist is far better understood and exploited by the oil industry than is that of the

hydrologist by the water industry. He may argue, not without reason, that any surface water project is incomplete and even inexpedient unless it can be proved superior to a ground-water scheme for the same area. In fact, in most cases the correct economic answer is a combination of the advantages of both sources.

Surface and Underground Water Exploitation

The recent great increase in knowledge and tremendous advances in technology are creating a new approach to water exploitation. Fresh water on the surface and fresh water underground are no longer considered as two separate phenomena but as an entity comparable to an iceberg, its smaller part visible, its larger part hidden below the surface, but both integral parts of the whole—changes affecting one being reflected in the other. Nothing exemplifies this character better than the new hydrological approach to springs.

Springs are considered as surface waters, but they represent outflows or overflows from subsoil reservoirs. As long as springs were regarded solely as surface water phenomena, improvements in the supply systems based on them were limited to cleaning the spring pools or to building shallow installations with a view to easing and concentrating the outflow, and thus to facilitating abstraction at the spring site. When springs began to be regarded primarily as ground-water phenomena, several important questions arose illustrative of this new approach. For example, does the spring outflow represent the maximum yield of the aquifer feeding it? If not, might not the yield be increased by drilling wells at some distance from the spring? Or, going one step further, if water is to be consumed somewhere within the catchment area of the spring, why let it flow underground to the spring and then carry it back on the surface to the points of consumption? Why not draw off the spring water through bore-holes at the place where it is required?

The technique of water exploitation is in fact changing along the lines indicated by these questions. If spring water is saline, it can often be 'freshened' by being taken out of the feeding aquifer at a point where salination has not yet become effective. If spring water does not emerge at a clearly defined spot and passes from the aquifer to the surface through colloidal layers, part of the water seeps upwards, is dissipated laterally in the soil and lost through evaporation. This type of spring evaporation wastes large amounts of water in arid zones. By converting such springs into groundwater, the water potential of the source can be considerably increased. This is done by abstracting the outflow at a certain depth below the ground and pumping at such a rate as to exclude the aquifer from direct contact with the superimposed layers.

An example of this type is the Ein Hatseva spring between the Dead and

the Red Seas—one of the best-known watering places and rest resorts in a desert region. This slightly swampy area was previously yielding a fixed amount of 8 m^3/hour of fresh water. Recently a well was drilled right at the spring-head to a depth of 70 m piercing the aquifer, which was overlaid by alluvial material; it now produces 36 m^3/hour of artesian water of the same quality as that of the spring. Although the outflow from the spring itself has slightly decreased, the total yield is five times greater than previously.

Accumulation, movement and storage of water, on the surface or below the ground, may now be regarded as natural phenomena which man can manipulate for his own benefit rather than as immutable conditions to which he must submit. Quantitative relationships between run-off, infiltration and evaporation can in many cases be radically changed if there is enough incentive for doing so. Water management is now conceived of not as an individual operation for a particular purpose, but as an economic and social enterprise in the broadest sense. The design of structures must take into account possible future demands and changes; in a relatively short time the emphasis may shift from urban to industrial supply, from power generation to irrigation, from local flood prevention to regional transportation of surplus water, from surface to underground abstracting, from importing water into deficient regions to draining saturated soils in the same regions, from artificially raising a water-table (with a view to obtaining a desired soil structure) to artificially lowering a water-table (for better infiltration), or lastly, from purely economic ends to social objectives, such as recreation.

In fact, water manipulation has become one of the principal means of improving a natural environment and making it fit for civilized life. It is also clearly one of the fundamental responsibilities of an organized society.

FUTURE PROSPECTS

How speedily can this new concept of water development be translated into practical achievements? It would be idle to pretend that there are not tremendous obstacles still to be overcome. These arise not merely from psychological or educational considerations, but also from age-old traditions in technique and organization and from political conflicts at national or international level. Attempts by the United Nations to create an international water agency on the lines of the World Meteorological Organization have not been successful so far, though water is certainly of no less importance than weather to the peoples of the earth. Reluctance to burden the still young United Nations Organization with too many tasks was no doubt a relevant consideration; perhaps another was the fear that an international water agency might become involved in the political tensions over river systems crossing national boundaries (Indus, Nile, Jordan, Danube, etc.). Some at

least of the objections of a political character might have been removed if more stress had been laid on the ground-water aspects of water development, for these affect national sovereignty to a lesser extent than do considerations relative to surface water.

In the field of international scientific co-operation the picture is brighter. Apart from the valuable work of Unesco's Arid Zone Programme in the study of water in dry regions, the International Association of Scientific Hydrology has made great efforts to foster the study of water on a scientific basis. The International Geological Congress, which met in Mexico City in 1956, set up an International Association of Hydrogeologists with a view to concentrating efforts on the study of subsoil water. The new technological outlook is also making itself felt in other related fields, such as drainage, irrigation, water engineering and water treatment, where research is being expanded and intensified.

Far less satisfying is the situation with regard to education and training. The demand for trained water scientists and technicians far exceeds the supply, and public as well as private bodies experience great difficulty in getting the professional guidance needed for the planning and building of water supply systems. The real bottle-neck is the lack of university and engineering college teachers sufficiently versed in modern hydrology. This accounts for the predominance of the self-made hydrologists—scientists coming from the neighbouring fields of physics, chemistry, agronomy, geology, geography and certain branches of engineering—and it is on such technicians that we shall have to rely for years to come. A student who wants to train in hydrology must literally pick up bits and pieces here and there and may still have to learn fundamentals even after he has embarked upon his professional career.

This fragmentation of training for an essentially simple and integrated discipline reflects the present lack of co-ordination with regard to water management, whether at governmental, regional or local levels. A functional division of water development operations may be justified; but the artificial division between departments dealing with surface and ground-water, and the frequent lack of co-ordination in the planning and execution of works for drainage, sewage, urban supply and irrigation, or in the management of rivers, lakes, canals and dams, have only served to create friction and conflict between opposing interests. The very purpose of large development schemes is to break down the walls between these literally watertight compartments.

The water industry as a whole also suffers both from a lack of norms, and from a widespread conservatism in outlook. When it is remembered that the water industry over-shadows all other industries in the volume of the raw material it handles, that investments in this industry now amount to the equivalent of 200,000 to 300,000 million dollars and are expanding at the

rate of 10,000 million dollars a year, it is difficult to understand why modernization is so slow in coming. Catalogues of supplies and services, the application of electronic computers and of automation, the establishment of certain legal rules for exploitation, the furthering of company-sponsored fundamental and applied research on a scale commensurate with needs, all of which are standard practice in the oil industry, have scarcely made their appearance in the water industry.

The most encouraging aspect of recent water development is the success of large and complex schemes carried out in various parts of the world, and the enthusiasm they have generated both among those who participated in the work and among those who benefit from it. Science and technology together with sound management have overcome the restrictions of tradition and created encouraging precedents for the future.

LECTURES AND MEETINGS

Technological Humanism

by

SIR ERIC ASHBY

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My first duty is to express gratitude to the Council for inviting me to deliver this lecture. My second duty is to explain to this audience why I accepted the invitation, for it is no light matter to take one's place in the galaxy of May lecturers. Nearly all my predecessors have been masters in the physical sciences or in engineering. I am a biologist who has turned to administration. My career could be regarded as one long disqualification for delivering a lecture before this Institute.

Nevertheless I accepted the invitation because I believe that modern technology is confronting us with an exceedingly perplexing biological problem. It lies in the field of human ecology. It is the problem of how men and communities can adapt themselves to an environment which is changing with unprecedented speed.

Let me introduce the problem by way of an antithesis between technology and heredity. Napoleon, who died only 136 years ago, was not able to cross the Alps any faster than Hannibal crossed them. Today you can have breakfast in London and lunch in Rome. Gladstone, who died less than two generations ago, was not able to reach more people with his voice than Demosthenes reached with his. Today a prime minister's voice can be heard in the homes of millions. Sixty years ago a ship was out of touch with the world as soon as it lost sight of land. Today a ship can sail into the Arctic and remain as close to the news as a pedestrian in Piccadilly. The rate of change in the last hundred years is of a different order from that in previous centuries; and the changes are not merely advances in technology: they are drastic transformations in the environment of man.

In contrast to this, man remains very much as he was when history began. He learns no more efficiently than a pupil in Plato's Academy learnt. He thinks no more deeply than Plato thought. His chromosomes are conservative

and resistant to change. He responds to new environments not by innovations in his heredity but by the marvellous adaptability of his ancient genetic heritage. This adaptability would be impossible if the only channel of inheritance from one generation to the next were through the sperm and the egg. In man—and in man alone—there is a second channel of inheritance. The accumulated knowledge and traditions of society are inherited not through the chromosomes but through education.[1] Education is the second channel of inheritance. Whether today's children will be able to cope with tomorrow's world depends largely on the inheritance of education which they receive. Over this channel of inheritance we have some influence and we can assume some responsibility; it is a responsibility which none of us would wish to escape, for not only are we the architects of this technological age: we are also the parents and grandparents of the children who have got to live in it.

This gigantic problem—the adaptation of society to a rapidly changing environment—confronts teachers of all kinds at every level of education. In this lecture I shall focus on one thin layer of the problem, namely one aspect of the higher education of technologists. This is the concern of universities, colleges of technology, and professional institutes such as your own, and it is specially important because technologists are now becoming the pacemakers for social change; communities which formerly developed on the initiative of princes, or bishops, or financiers, or soldiers, now develop on the initiative of technologists. It is no exaggeration to say that the quality of education to be given to technologists may deeply influence the future of the West.

A great deal has been written recently about the desperate necessity to increase the annual output of technologists in Britain.[2] This audience does not need to be reminded of this necessity. We are all of us persuaded that the quantity of technologists must be increased. What we are not at all clear about is the quality of educational inheritance which technologists should receive. This lecture is concerned with quality, not quantity; what I propose to offer you in particular are some reflections on the content of education for higher technology in Britain. One warning before I begin: lectures on education are unlike lectures on metallurgy, for men have been thinking about education for over 2,000 years, and some of their thinking never becomes out of date. Anything worth saying has already frequently been said. Anything hitherto unsaid should be regarded with the greatest suspicion.

It is first of all necessary to recollect how technological education arose in

1. Education is here used in the widest sense, to cover the transmission of tradition and culture by instruction, precept, or imitation. The theme is as old as Plato. It has recently been used with good effect by T. Dobzhansky, *The Biological Basis of Human Freedom*, Oxford, Clarendon Press, 1956.
2. See e.g., *Scientific and Engineering Manpower in Great Britain*, London, H.M. Stationery Office, 1956; and *Engineering and Scientific Manpower in the United States, Western Europe, and Soviet Russia*, Washington, D.C., U.S. Government Printing Office, 1956.

this country. The first Industrial Revolution was accomplished without scientists or technologists. Bramah and Maudslay, Arkwright and Crompton, the Darbys of Coalbrookdale and Neilson of Glasgow: these men had no systematic formal education in technology. While wars absorbed the energies and dissipated the capital of continental Europe, these men and others like them built up British industry until it had no rival in the world. Our industrial strength lay in our amateurs and our self-made men: the 'cultivator of science' (as he was called), the craftsman-inventor, the mill-owner, the ironmaster. It was no accident that the Crystal Palace, that radiant symbol of the supremacy of British technology, was designed by an amateur. In 1851 most people in authority saw no danger in the fact that Britain had no state system of primary education (a third of the population was still unable to read or write); or in the fact that there was scarcely any science teaching in secondary schools ('it is plainly out of the question', said Moberly of Winchester, 'that we should teach chemistry'); or in the fact that there were no opportunities for the study of higher technology except a little in London and in Scotland. It did not seem worth while to spend money on popular education, for industry was flourishing and manpower was cheap; nor did there seem to be any reason why the well-to-do classes (who were concerned with administration and management and not with mere technical details) should depart from their traditional education in the classics. Notwithstanding the Industrial Revolution, science and technology still played practically no part in higher education. Not long before the 1851 Exhibition the professors of physics and chemistry in Oxford had asked to be excused from lecturing altogether because there were so few students; and although the Cambridge science tripos was established in 1851, there were on the average only about nine successful candidates a year for the first twenty years.[1]

Fortunately there were men of foresight who were unhappy about this situation. The Royal Commission on Oxford University tried to encourage Oxford to pay attention to the physical sciences by saying that unless 'the clergy and gentry . . . are encouraged to keep pace with the progress of society at large . . . they may find themselves placed below persons in many respects inferior and an opposition may arise between Physical Science and other branches of knowledge'.[2] The Royal Commission on Cambridge University was even more precise: 'It may be quite true', the report says, 'that many of the practical . . . details of civil engineering may be best learned in the offices of engineers . . . but the knowledge of mathematics and of mechanical principles, as involved in the estimate of . . . the effects of elasticity, and generally of the operation of forces and pressures is so neces-

1. Some interesting information on this and related topics has recently been assembled by D. S. L. Cardwell, *The Organization of Science in England*, London, Heinemann, 1957.
2. *Report of the Royal Commission on the University of Oxford*, 1852.

sary . . . that no amount of practical skill and experience can ever replace the want of this theoretical knowledge.'[1]

These admonitions, and many others like them, made very little impression on the managers and mill-owners and ironmasters of Britain; these men were prepared to agree that science and technology were appropriate subjects for artisans and the lower middle class, but not for their own sons. And so, when the Society of Arts and the new government Department of Science and Art did set up schemes to encourage scientific education, these schemes were almost exclusively for the benefit of artisans and the 'labouring poor'. Clearly admonitions were not enough; a much more powerful impact was needed to overcome public inertia to technological education.

That impact was provided by the International Exhibition held in Paris in 1867. Britain had won awards in nearly every class in the 1851 Exhibition, but in the 1867 Exhibition she had to be content with a bare dozen awards. No longer was there the reassurance of easy industrial supremacy. Instead there was alarming evidence that Britain had made little progress in the peaceful arts of industry since 1851 and that Continental countries had now become very serious competitors.[2] For example, a building was being put up at Glasgow with iron girders from Belgium, and it was asserted by Lyon Playfair that Belgian girders were cheaper because the Belgians had introduced economies depending on chemical analysis of the ore and limestone and fuel. British fabrics were being sent to France to be dyed on the ground that the French had techniques superior to our own. The French explained this by saying 'the foreigner thinks it is our water and our sunshine, but we say it is our chemistry'.[3]

What had happened in the interval between the two exhibitions to bring about this change? There were many causes at work, but the chief cause undoubtedly arose from Britain's monopoly of much of the 'know how' she had acquired during the Industrial Revolution. Up to 1825 it was a penal offence to enlist English artisans for employment abroad. Well on into Queen Victoria's reign, the export of spinning machinery to foreign countries was prohibited. When Continental countries began to build railways and mills and factories, they found it extremely difficult to obtain access to British techniques and practices. They had to make up for half a century of lost time. Their response was to produce a new species of professional man: the manager-technologist. To this end they established polytechnics with the specific purpose of training not the rank and file of workers, but engineers, designers, chemists, and potential managers for industry. In Zürich, in Dresden, in Delft, even in the United States, there arose in mid-century technological institutes which had no parallel in Britain. Their function is well

1. *Report of the Royal Commission on the University of Cambridge*, 1852.
2. Letter form Dr. Lyon Playfair to the Rt. Hon. Lord Taunton, *J. Soc. Arts*, 1867, Vol. 15, p. 477.
3. *Report of the Select Committee on Scientific Instruction*, 1868.

summarized by the words used to describe the Massachusetts Institute of Technology (founded in 1864) as a place 'intended for those who seek administrative positions in business . . . where a systematic study of political and social relations and familiarity with scientific methods and processes are alike essential'. In addition, almost every manufacturing town on the Continent had its continuation school where workers were obliged to extend their education up to the age of 16 by part-time day-release. And beside these there were specialist technical schools such as the Metallurgical School in Bochum (in Rhine-Westphalia), where potential managers and supervisors in the local factories and mines were released from industry for three years' full-time study.[1]

The prime purpose of this widespread system of technological education abroad was not humanitarian: it was to enable Continental countries to catch up and to overtake British industry. Accordingly in the polytechnics emphasis was laid on a combination of science, technology, and general knowledge, suitable for men who would direct technical policy. Already by 1867 this experiment had begun to yield results. The results were obvious to Britain, and it was this challenge from the Continent, rather than a demand from industry at home, which drove Britain finally to set her educational house in order.

The leeway to be made up was truly appalling. Continental countries like Prussia had enjoyed compulsory primary education and compulsory further education with day-release for over a generation; and for years the *Realschulen* of Germany had made science an integral part of secondary education. England in 1867 had no State school system, primary or secondary, and no general compulsory education. Continental universities were generously financed by the State, and many of them had well-established laboratories in close touch with industry. Bunsen in Heidelberg, Kekulé in Bonn, Liebig in Munich, Wöhler in Göttingen: all these chemists were training men who were accepted for industrial posts. England in 1867 was contributing scarcely any money by way of public funds to her universities, and her universities were contributing scarcely any technologists to industry. Per head of population, England had only about a quarter of the number of students Germany had. There was no Clarendon Laboratory in Oxford nor Cavendish Laboratory in Cambridge. Owens College in Manchester, sixteen years after its foundation, had only 113 students. Efforts of the Prince Consort to establish an industrial university in London had up to that time failed.

Because of this leeway, England could not meet the challenge from the Continent by building polytechnics; for she had no adequate foundation of schooling on which to build. And so, even after the need for technical and technological education had been realized, the response was slow and un-

1. A description of this metallurgical school is given in the *Second Report of the Royal Commission on Technical Instruction*, 1884, p. 117.

certain. In 1870 the Government introduced compulsory primary education. But Parliament was still unwilling to support trade schools and technical schools; it was the Livery Companies which first undertook to assume this responsibility. In 1867 they set up the City and Guilds Institute, which fathered not only the first genuine technical college (at Finsbury) but (at South Kensington) the first genuine institute for higher technology. Not until 1889 did public authorities take over elementary technical education, and even then education in higher technology was not made a public responsibility; most of it was left to the universities and university colleges.

Here—in my opinion—is one clue to an understanding of our present curricula in higher technology. The spur to technological education in universities was not in the first instance a demand from industry for scientifically trained managers; it was the determination of a few farsighted men to create a supply in anticipation of a demand. Accordingly, the pioneers of technological education in universities found themselves having to justify their subject on academic and not utilitarian grounds. They could not prove to their academic colleagues that higher technology was useful, and so they had to make it appear respectable. Accordingly they felt obliged to follow the fashions set by more venerable faculties. (Even as late as 1861 the University of Glasgow, which claims to have the oldest university chair of engineering in the Kingdom, did not consider engineering to be 'a proper department in which a degree could be conferred', and it remained for years in the Faculty of Arts.) Therefore when, under the influence of German scholarship, specialization became fashionable, technology followed the fashion. Part of the price paid for following the fashion was a narrowing of the curriculum in every discipline—not only in technology. No longer was it necessary for a man taking the classical tripos at Cambridge to pass first a tripos in mathematics and mechanics. No longer did the London B.A. require some knowledge of both the humanities and the sciences. The universities assumed (and with some justification in those days) that secondary schools would provide a balanced general education and that universities could concentrate on turning their best men into experts: experts in classical philology, or history, or chemistry. Where the arts and sciences led, technology followed, and the trend in higher technological education was consistent with the pattern of British industry. In Continental countries, many technological experts found themselves in the board-room, or acting as administrative civil servants. Their education prepared them for these responsibilities. In Britain, administration and policy-making remained largely in the hands of men with no technological training. The chemist from Roscoe's laboratory in Manchester or from Graham's laboratory in London might look forward to a career in industry as a chemist. But there was no great demand from industry to equip him to manage, or to be responsible for human beings. Higher technological education abroad was from the

beginning intended to produce not only experts but also managers and leaders in industry. In the British economy of the 1860s and 1870s, there was no shortage of men for the board-room: the shortage was in the design office, the laboratory, and the plant; therefore the pattern of higher technological education set in this country at that time was one to produce experts to advise on policy, not leaders to make policy. With modifications, accretions, and improvements, that pattern has persisted ever since.

This long historical digression enables us to diagnose the present state of higher technological education in Britain. On the one hand, there are grounds for satisfaction: there is no reason to believe that any foreign university can teach the practice and techniques of science and technology better than they are taught in such places as Imperial College or Manchester or Cambridge. Regarded as a preparation for doing nothing but organic chemistry, or non-ferrous metallurgy, or light electrical engineering—in other words, regarded as a production line for highly differentiated experts—there is nothing much wrong with technological education in Britain. On the other hand, grounds for anxiety do exist, for buried at the foundations of our system for educating higher technologists there are two assumptions, both of which are wrong. The first assumption is that the technologist has had a balanced schooling with a thorough grounding in what are vaguely called 'the humanities'. This assumption may have been justified fifty years ago.[1] Today it is no longer justified. The would-be technologist has had to decide in his early teens to go up the school on the science side and not on the classical side, and he has to specialize for ever afterwards. No secondary education is so overspecialized as ours in Britain today. The second assumption is that the technologist is to become and to remain an expert to serve the manager, never to become a manager himself. This assumption, also, is no longer justified; and in the Second Industrial Revolution, which is upon us now, it will become an utterly obsolete assumption. Because these two assumptions are still made, the question of including the humanities in higher technological education is still not taken seriously. True, it is a subject worn threadbare in graduation addresses, educational conferences, and academic pamphleteering, but (with one or two exceptions) it has not yet become the subject for faculty decisions or senate resolutions. Ask professors of technology what they are doing about it, and they reply that the curriculum is already overloaded, and nothing more can be added. Ask the advice of arts professors, and some of them will reply that a faculty of arts

1. And not only in the humanities: it is now forgotten that the *Sixth Report of the Royal Commission on Scientific Instruction* (1872-75) recommended unanimously that in all public and endowed schools six hours a week should be devoted to science and that science should constitute one-sixth of the leaving examination. Such a recommendation would today be regarded as unreasonable by most secondary schools. It is important to recollect that the curriculum in most secondary schools today is much less balanced than it was nearly three generations ago.

is not a faculty of culture; it has no contribution to offer toward civilizing the 'savage technologist'. The historian (they say), pursuing his minute inquiries into medieval charters, has no more relevant contribution to make to technological education than the biologist has, assiduously analysing the urine of mice. There are, you see, resistances from both sides: faculties of technology cannot find room for the humanities; faculties of arts—in this context at any rate and if we are to believe some arts professors—do not regard themselves as trustees responsible for communicating the values and traditions of Western civilization to other faculties.

Contrast this with the training being given to technologists in other countries. I quoted just now the purpose of the Massachusetts Institute of Technology: to train men for posts where 'a systematic study of political and social relations and familiarity with scientific methods and processes are alike essential'. The student at the Massachusetts Institute of Technology must devote a considerable portion of his time throughout all four years of his course to English composition and literature, history, psychology, international relations, and economics; and these subjects are taught in a way which is relevant to technologists. In the Swiss Federal School of Technology at Zürich, third- and fourth-year students include in their course law, economics, and management, and there is a Department of General Education with twelve professorships covering foreign languages, philosophy, history, law, and political economy. All students must register for at least one course in this department. In the Technical University of Delft, there is a so-called *Studium Generale,* which provides lectures on religion, philosophy, music, and art; something similar was already being done there over 70 years ago, in the 1880s. Even technological institutions in the Soviet Union devote some time to the humanities and the social sciences.[1] The British Commonwealth has not ignored these examples: in the New South Wales University of Technology there is a Department of Humanities, with a full professor at its head. Even some English technical colleges have introduced an element of the humanities into their courses.[2] Nevertheless, universities in Britain are not yet persuaded that the humanities are an essential ingredient in higher technological education. Many universities do indeed arrange opportunities for students to broaden their interests through voluntary attendance at lectures on art and music and the like. This is admirable, but it is a very different thing from recognizing certain humanistic studies as an integral part of a technologist's formal higher-education.

At this stage I must ask you to accompany me into another digression. It is a thankless task to define the humanities, but when I talk about including

1. See N. de Witt, *Soviet Professional Manpower,* Washington, D.C., National Science Foundation, 1955.
2. *Liberal Education in a Technical Age,* London, 1955.

the humanities in higher technological education, there must be no doubt about which humanities I mean. I do not mean courses on the appreciation of poetry or music or pictures. In my experience the student who whistles Bartok or reads Dylan Thomas or buys a Picasso reproduction for his room has come to care for these artists without any help from formal university courses. That sort of appreciation we can safely leave to the students themselves (although we should certainly encourage it in every way we can); it is just as likely to appear among students of technology as among arts students. (In fact, there's something to be said for not being an arts student if you care for literature, because you then avoid the earnest but misguided species of arts don who believes that a student cannot read *Anna Karenina* or *King Lear* or *The Turn of the Screw* unless some university teacher has first interposed himself between the student and Tolstoy or Shakespeare or Henry James, to deaden the impact of genius by explaining what these writers really intended to say to their readers.) We can safely disregard the sentimentalists who say that faculties of technology fill the minds and starve the souls of the young. There is no evidence that the souls of technologists are starved. There is evidence—as I hope to persuade you—that the minds of most technologists are deficient in certain arts subjects needed for their professions.

So let us be quite hard-headed about the humanities which should be included in higher technological education. There are four criteria for selecting them. First, they should not include subjects which can and ought to be taught at school. Second, they should be taught as genuine humanities, that is to say they should deal with the creative and social acts of man, and particularly with value-judgements about these acts: man's ideas of right and wrong, of good and evil, of justice, freedom, and government. Third, they should be taught in such a way as to be relevant to the contemporary world and to technology. (This does not mean we have to invent newfangled humanities: nothing could be more relevant to the contemporary world than parts of Aristotle's *Politics*.) Fourth, humanities at this level of teaching should be instruments to enhance the individuality of students, to resist that levelling of differences in taste and personality, that tendency to increase social entropy, which is a melancholy consequence of the modern techniques of mass communication.

Indeed, what is needed is nothing less than a revision of the idea of a liberal education. The *Oxford Dictionary* defines liberal education as education fit for a gentleman. That is still an acceptable definition; it is the idea of a gentleman which has changed. A century ago, when Britain awoke to the need for technological education, a gentleman belonged to what was called the leisured class. The occupations of his leisure did not require any knowledge of science or technology. Modern gentlemen do not belong to the leisured class. Many of them work something like a seventy-hour week,

and more and more of them are finding that their business requires expert knowledge. Even members of the House of Lords find themselves called upon to make decisions about radio-active fall out, and overheating during supersonic flight, and the strontium content of bones. Ministers and senior civil servants have to deal with highly technical policy in DSIR and the Ministry of Supply. Even such a gentlemanly subject as the state of the River Thames cannot be understood without some knowledge of oxidation and reduction, detergents, and the biochemistry of sewage. Dare I suggest, in this audience at any rate, that in order to be a gentleman nowadays, one has to be something of a technologist?

But technology alone will not make a modern gentleman. And this brings me to the core of my lecture. It is nothing new to suggest that technologists should know something of the humanities. I want to go further; I want to suggest that, for the gentleman technologist, certain of the humanities are an integral part of technology. 'Technological humanism' is not just a rhetorical phrase: it has genuine content.

For technology is inseparable from men and communities. In this respect technology differs from pure science. It is the essence of the scientific method that the human element must be eliminated. Contrary to the assumptions of some people, science does not dispense with values; but it does eliminate the variability of human response to values. It concerns itself only with phenomena upon which all qualified observers agree. It describes, measures, and classifies in such a way that variation due to human judgement is eliminated.

Unlike science, technology concerns the applications of science to the needs of man and society. Therefore technology is inseparable from humanism. The technologist is up to his neck in human problems whether he likes it or not. Take a simple example: the civil engineer who builds a road into a new territory in tropical Africa. He may assert that it is not his business to take into account the effect his road will have on primitive villages up-country; but his road is in fact a major experiment in social anthropology. He does not need to be a professional anthropologist, but he cannot afford to be utterly ignorant of the implications of his work. He is a technologist, not a pure scientist: the social consequences of his work are therefore an integral part of his profession. Take another example from one of the most ancient technologies: medicine. Chemotherapy and preventive medicine and contraceptives between them have enormously altered the pattern of family life. The next generation will inherit from us a surplus of elderly people. This situation sets problems which have given rise already to a new subject called gerontology. Now the problems of gerontology are not merely scientific; they involve some of the perennial issues of humanity—family affection, group loyalty, and social justice. The practitioner in social medicine is a technologist: he cannot repudiate these involvements.

Long ago, in *Science and the Modern World,* A. N. Whitehead saw the

essential unity between technology and humanism. Listen to what he said: 'A factory with its machinery, its community of operatives, its social service to the general population, its dependence upon organizing and designing genius, its potentialities as a source of wealth to the holders of its stock is an organism exhibiting a variety of vivid values. What we want to train is the habit of apprehending such an organism in its completeness.'

The habit of apprehending a technology in its completeness: this is the essence of technological humanism, and this surely is what we should expect an education in higher technology to achieve. How is it to be achieved? Ninety years ago, when Thomas Henry Huxley was giving evidence before a Select Committee on Scientific Instruction, he poured scorn on the universities because they made literature and grammar the basis of education and (as he put it) 'they actually plume themselves upon their liberality when they stick a few bits of science on the outside of the fabric'. It will not do for us, ninety years later, to reverse the process and to plume ourselves upon our liberality when we stick a few bits of the humanities on the outside of the fabric of higher technology. That would not achieve our purpose; it would only generate in students a contempt for the humanities, analogous to the contempt which public schoolboys in the 1860s had for science. It is no good trifling with this problem. We must cut the path to a liberal education *through* a man's specialism, not by by-passing it for an hour or two a week.

It should be our business in higher technological education to persuade students that they cannot practise technology without continually reflecting upon its social implications, and that some understanding of the humanities is essential to this reflection. For a metallurgist to take a course in general history in order to acquire a little culture is an innocent but not necessarily a very profitable amusement. But if the metallurgist studies the social and economic history of the Industrial Revolution; if he learns how the making of iron followed the forests across Europe until coal replaced charcoal; if he realizes how mining and the building of railways and canals stimulated the study of geology, and how this in turn brought men face to face with the evidence for organic evolution; if he considers the effect which the introduction of electric power has had on the distribution and lay-out of factories, and the effect which aluminium alloys have already had (through world transport) on the conduct of diplomacy: then history becomes integrated with metallurgy; his humanism becomes a relevant part of his day-to-day thinking. May I be allowed to quote to you a paragraph I have already published on this matter:[1]

'Suppose a student decides to take up the study of brewing: his way to acquire general culture is not by diluting his brewing courses with popular lectures on architecture, social history, and ethics, but by making brewing

1. *Research*, 1955, Vol. 8, p. 419.

the core of his studies. The *sine qua non* for a man who desires to be cultured is a deep and enduring enthusiasm to do one thing excellently. So there must first of all be an assurance that the student genuinely wants to make beer. From this it is a natural step to the study of biology, microbiology, and chemistry: all subjects which can be studied not as techniques to be practised but as ideas to be understood. As his studies gain momentum the student will naturally become interested in the economics of marketing beer, in public houses, in their design, in architecture; or in the history of beer drinking from the time of the early Egyptian inscriptions, and so in social history; or in the unhappy moral effects of drinking too much beer, and so in religion and ethics . . . It appears today as though technology will become the key to general culture. Technology: not science; because scientific systems are too self-contained—they exclude too many factors, including man—whereas the technologist has to make something which requires as its ingredients not only science but an understanding of popular art and commerce, of psychology, something of morals and justice, and skill in the art of communication. A technologist who cannot weave his technology into the fabric of society is not first rate; a technologist who can weave his technology into the fabric of society can undoutedly claim to have . . . general culture.'

If these arguments are acceptable, the mischievous antithesis between specialization and general culture disappears.

I must not shrink from the last step. Anyone can blow bubbles about education for an hour. But educational bubbles have no value unless they can be stabilized; and the only stabilizers are curricula and time-tables. 'Very well' (you will be saying) 'what does all this involve in (for example) the weekly time-table of a civil engineer in a British University?'

I shall try to tell you. It involves a little more time in the undergraduate course, secured either by cutting some subjects down or by lengthening the course. Since Britain is about the last country in the world to attempt to train technologists in three years from the post-intermediate stage, I would not regard this as a very grave obstacle. It involves a little more money. Since it costs £45,000 to train a bomber pilot[1] and about £1,500 to train a technologist, I would not regard some additional cost as a grave obstacle either. It involves some newly designed courses which are within the capacity of lecturers normally to be found in faculties of arts, law, and economics.

Here are some examples of the choice of courses these lecturers might offer to technology students:

(a) A course on ethics and jurisprudence, with some discussion of the principles of law and justice (such as might be given by a legal philosopher).
(b) A course on industrial and social history of Europe since the seventeenth

1. *The Times*, 13 February 1957.

century, with emphasis on the social effects of technological change (such as is already offered at the Dutch Institute of Social Studies at The Hague).

(c) A course on political theory, political institutions, and the history of guilds and trade unions (this would be an opportunity for medieval as well as modern historians) .

(d) A course on industrial psychology.

(e) A course on sociology and social anthropology.

(f) A course on the history of technology, including readings from the classics of science and technology (this might go some way toward meeting one criticism of all present courses on technology, namely, that it is possible to get a first-class honours degree without ever having read a work of genius).

(g) A course on linguistics and communication (a development of some of the material contributed to the Communication Research Centre at University College, London).[1]

Not every student should take every course. It would be very much better that a student should pursue one rigorous course over a period of (say) two years (with the discipline of reading and essay writing and examination which should be required in such a course) than that he should ramble in a dilettante fashion among several courses. The courses would have to be prepared specifically for technologists, and it is important that they should be used as an opportunity for exercises in communication between students; for inarticulateness is an occupational disease among technologists; and it is a disease which I believe could be very much relieved by this simple prophylactic treatment.

Among the criticisms which are likely to be levelled against such courses as these, there is one criticism I wish to anticipate. Courses like these (it will be said) are not detailed enough to give the technologist mastery in any of these fields, but they may give him the illusion of mastery. It is not a serious criticism, for the same might be said of most university courses, particularly in the humanities: a student who has passed an examination in English usage has no right to consider himself a master of English prose. Nor, I think, is it valid criticism, for it will have to be made clear that the purpose of the courses is not to train practitioners but to provide ideas which will act as templates in the mind. On these templates the technologist can shape his own thinking from his own experience; without them he will be unable to comprehend his technology in its completeness.

'Liberality in education', Samuel Alexander once wrote, 'is a spirit of pursuit, not a choice of subject.' If technologists are to enter fully into their responsibilities in the world of tomorrow, they have to adapt themselves not

1. *Studies in Communication*, London, Secker and Warburg, 1955.

only to novel technologies: they must also be able to adapt themselves to the social consequences of the novel technologies. Their prospects of adaptation certainly depend in part on the spirit with which they pursue technology as undergraduates. To pursue technology in a spirit of liberality, they need not only a thorough training in the theory and practice of technology (they get that already); they need also an understanding of men and communities such as is acquired through literature and history and the social sciences.

Let me end by summing up in one minute what I have been trying to say for an hour. All industrial peoples have to solve a great problem in human ecology, namely how to adapt themselves, through the second channel of inheritance, to the social climate which is being created by modern technology. Technologists have a special responsibility to solve this problem for themselves and to reflect on its implications for their fellow citizens. I am persuaded that the solution for technologists lies through the inheritance of education they receive, and I am persuaded that the appropriate education for higher technology should be one which does for contemporary civilization what our traditional classical education has so successfully done for the civilizations of Greece and Rome.